G.E.C. Journal

VOL. I. MAY, 1930 No. 1.

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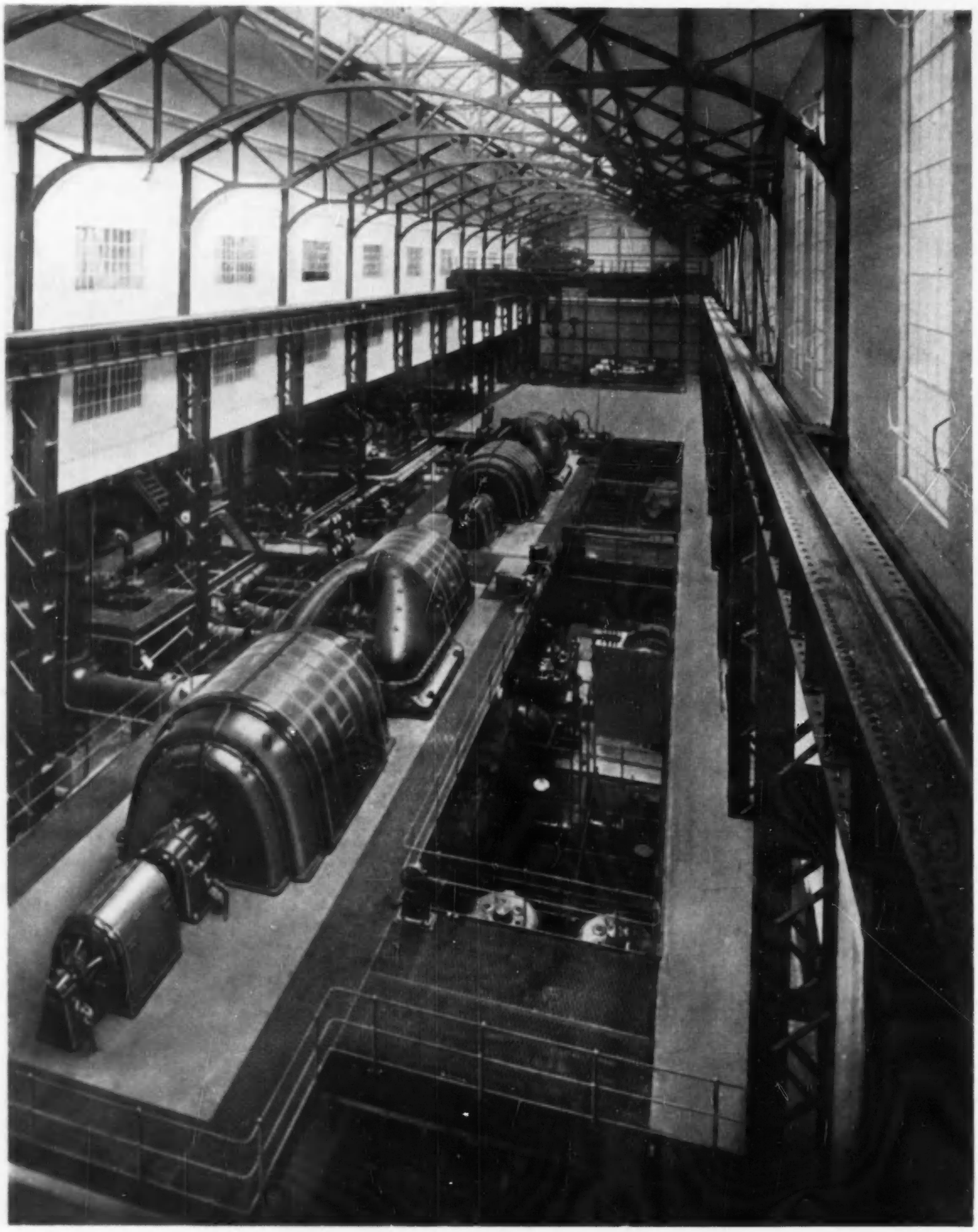


HAMS HALL POWER STATION.

Two 37,500 kVA turbo-alternators installed in the new power station of the Birmingham Corporation. They were put into service towards the end of 1929, and generate at 11,000 volts, 3 phase, 25 cycles, 1,500 r.p.m.

G.E.C. Journal

VOL. I. MAY, 1930. No. 1.

FOREWORD.

By SIR HUGO HIRST, BART.,
Chairman and Managing Director.

WHILE I can claim no credit for the initiation of this new venture, I rejoice that the need for it has been realised within our Organisation, and has called forth the energy and enthusiasm required to found a periodical with so high a purpose as the G.E.C. Journal.

The object of the journal is to make known to the G.E.C. and its friends in the first place, and to the world of science in the second place, the studies carried on in our Technical Departments, our Research Laboratories and Development Departments, and the technical achievements resulting from them. From two points of view, this is an object which commends itself to me. I have always held the broad conviction that the policy of secrecy in business is a mistake, that modern business should be systematically articulate about its activities, technical as well as commercial. Such a policy is, I believe, necessary in order to inspire confidence and to enable the enterprise to render its full service to the community.

The G.E.C. from its earliest days has acted upon this policy. Its catalogues have never been mere records of prices and discounts; they have always contained the fullest details of the apparatus concerned. Indeed, our first electrical catalogue, issued in 1887, boldly invited our friends "to avail themselves of our aid and to write to us for information upon any subject related to electricity." This was the line taken when the G.E.C. was mainly a trading concern, and it was continued when the Company entered upon the manufacturing field. Then the technical and commercial departments of the business collaborated in the production of bulletins and articles for the Press which had both a theoretical and a practical appeal. Our engineers were also active in reading papers before various technical and engineering institutions.

This collaboration was in operation before the post-war period which saw the establishment of our Research Laboratories at Wembley, and of large and well-equipped Development Departments in our factories. A great deal of original work—much more than is generally realised—had already been done in various directions, in connection with such vital inventions as electricity meters, Nernst and Osram lamps, arc lamps and carbons, searchlights and batteries, three-phase motors, rotary converters, and other apparatus. But for the dominating impression conveyed by the rapid progress of the supplies and general business of the Company, these technical and scientific achievements would have been more widely appreciated at their true value.

With the splendid equipment which we have now for some time possessed for research both in pure and applied science, and for experimental work in every department of electrical engineering, our pioneer efforts have increased enormously in their scope and importance. Lamps, valves, automatic sub-stations, high speed turbo-generators, pulverised fuel plants, extra high tension cables and switchgear, overhead transmission, large transformers, automatic telephony and the apparatus for totalisators, the photo-electric cell, and appliances for "Talkies," ebonite and moulded insulating material, alloys for special purposes, oil engines, Diesel locomotives, electric ship propulsion equipment; these are only a few of the problems we have been attacking with the finest instruments of research in the hands of experts with the highest qualifications. In many cases the processes of study carry us over

the borderland of engineering into the region of speculative science. In all cases both the investigations and the results have an interest not only to the members of the G.E.C., but also to the scientific world at large. It is difficult even for G.E.C. men to visualise all the intricate problems on which we are engaged; much more so is it for the outside observer to realise the range and volume of our operations.

No form of publication previously undertaken by the G.E.C. provides an adequate platform for the expression of this organised activity, on which between £100,000 and £200,000 is being spent each year. The bulletins and other literature already mentioned had a practical and commercial aim. The *Magnet Magazine* published at our headquarters and also by Overseas Branches; the *Loud Speaker* and the *Cable* issued by the Coventry and Southampton Works respectively, have a social aim, providing an invaluable connecting link among our 25,000 employees and between them and the management. Only incidentally and superficially do they touch on our achievements in research and development.

Clearly, therefore, the time has come for the G.E.C., as the most important electrical manufacturing combination in the British Empire, to come into line with similar concerns in other parts of the world and prepare a worthy record of its scientific and technical activities. I am confident that our contributions to the store of scientific knowledge and the cause of scientific progress will be of the highest value. Our appeal in the first instance will be to the engineers in all parts of the world who use our products; we hope to assure them, by the originality and technical excellence of our subject-matter that the G.E.C. is neglecting no avenue along which any possibility of useful advance is open to the trained scientific pioneer. But our real purpose is broader than that. We feel that in mobilising the best scientific and technical brains available for the pursuit of discoveries in every branch of electrical engineering, we are serving much more than the interest of the G.E.C. We are adding to the common stock of scientific knowledge. Modern science has become very highly specialised, but there is no natural barrier between the various departments of study. All are closely inter-related; and the results achieved in one department may have revolutionary effects upon others. It is therefore of the utmost importance that our specialists should, through such a medium as the G.E.C. Journal, make their experiments and speculations known to the whole community.

I trust, moreover, that the Journal will be specially welcomed in Technical Schools and Universities. It has always been my endeavour to get into closer contact with these sources from which we must draw the fresh trained minds necessary to continued industrial and technical progress. Not only should the contents of the Journal be of assistance in the research work undertaken by our Universities, but they should inspire many members of the coming generation with enthusiasm for the fascinating labour of the electrical pioneer.

Let me, in conclusion, express the hope that the contributions to the Journal will reflect the ever-growing importance of the G.E.C. within the electrical industry, and will breathe the spirit of understanding of the great part which the electrical industry is destined to play in the development of our country and indeed of the whole Empire.

The Research Laboratories of The General Electric Co., Ltd., Wembley, Middlesex.

Electrical Progress in 1929.

PROGRESS in the electrical industry during 1929 was steady and continuous, much development work of importance being undertaken, while many installations of considerable magnitude were completed both in this country and overseas. The contribution made to electrical progress by the G.E.C. during the period under review contains many features of considerable interest, and in this article it is proposed to direct attention to the more outstanding achievements of the company.

Reinforcing the whole of the activities of the G.E.C. is the company's Research Laboratories at Wembley, at which is undertaken not only experimental work directly associated with improvements in the company's products and the introduction of new apparatus, but in addition, that investigation of the scientific principles underlying the electrical engineering industry, so vital to future progress.

RESEARCH.

In view of the important part which the Wembley Laboratories play in the electrical industry, it is proposed first to deal briefly with some of the results of the activities there during last year. In connection with overhead transmission lines, plant has been erected for testing towers up to 100 feet high. Eight pulls of 15 tons each can be applied in one direction, with another eight of 10 tons each at right angles to the first series, the force being measured by remote control instruments housed together in a control room. During the past year the towers for the South East England and Mid-East England schemes of the "National Grid" of 132,000 volt transmission lines have been tested on this plant, and towers for further schemes are now under test. Tests have also been made on different types of foundation for these towers. There is also a conductor test plant upon which vibration and other mechanical tests are being carried out on the conductors and fittings for overhead lines. A length of over 250 feet of conductor can be accommodated for these tests and tensions up to 11 tons may be applied.

In the field of illumination the series of asymmetric reflectors has been extended for use with low wattage lamps. These enable directional lighting to be combined with a sharp cut-off which diminishes glare. Improvements in lamps have allowed non-ventilated lanterns to be used in sizes up to 500 watts, thus eliminating the deposition of dirt on the lamp and reflector.

A new type of photo-electric cell has been developed, which gives ten times as much current for the same white light illumination as the most sensitive cells previously made. In addition to this, it has great sensitivity in the infra red. A new type of single valve amplifier has also been developed for use with photo-electric cells to run directly off mains (A.C. or D.C.) and has an output of 10 milliamps. This amplifier has been applied to the automatic lighting of street lamps.

Photo-electric methods of photometry have been worked during the year under continuous service conditions and have proved very satisfactory, both accuracy and speed of operation being increased.

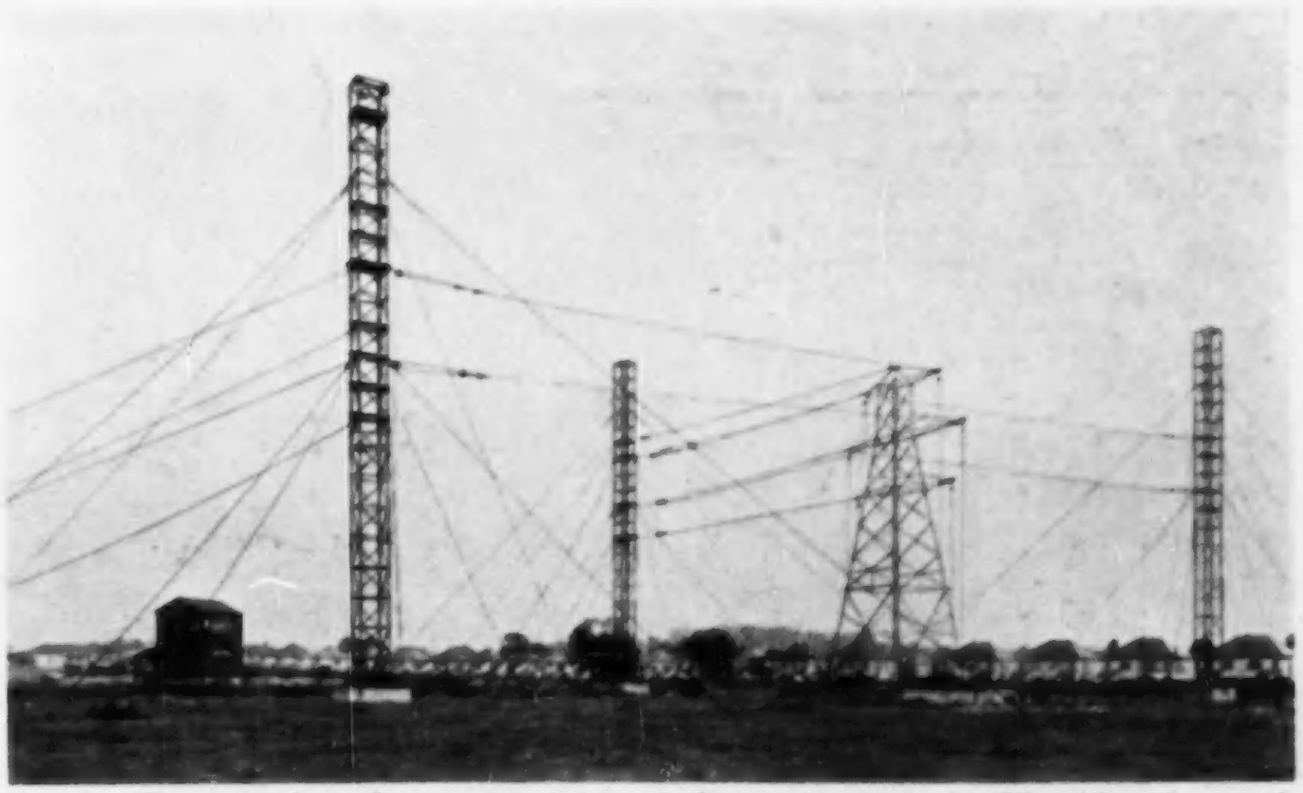


Fig. 1.—Testing plant for power transmission towers at the Wembley Research Laboratories. Eight pulls of 15 tons each can be applied in one direction, with a further eight of 10 tons each, at right angles to the first series.

Apparatus has been devised utilising photo-electric cells for the measurement of colour temperature and luminous output. Both temperature and lumen scales are linear, so that calibration of the apparatus is greatly facilitated. A photo-electric polar distribution apparatus is in course of development, in which automatic gear is used for plotting the results in the form of a polar curve.

Further steps have been made in the evolution of high power cooled anode valves to meet more exacting conditions, and to handle higher power. The factors controlling equal performance of units operated in parallel have been studied, and the predictions of life performance made in past years have been verified.

Research work has been undertaken in wireless receiving valves designed for operation on A.C. mains. The characteristics of the indirectly heated cathode types have been improved and their cathode-heater power consumption reduced. The number of types of indirectly heated cathode valves has been increased to meet the requirements of all stages in a receiving set, and now includes the screen-grid valve.

Some other work has been concerned with the technique of acoustic measurements applied to electro-acoustic problems of various kinds, while new methods of quantitative measurement of the working properties of glasses at high temperatures have been evolved.

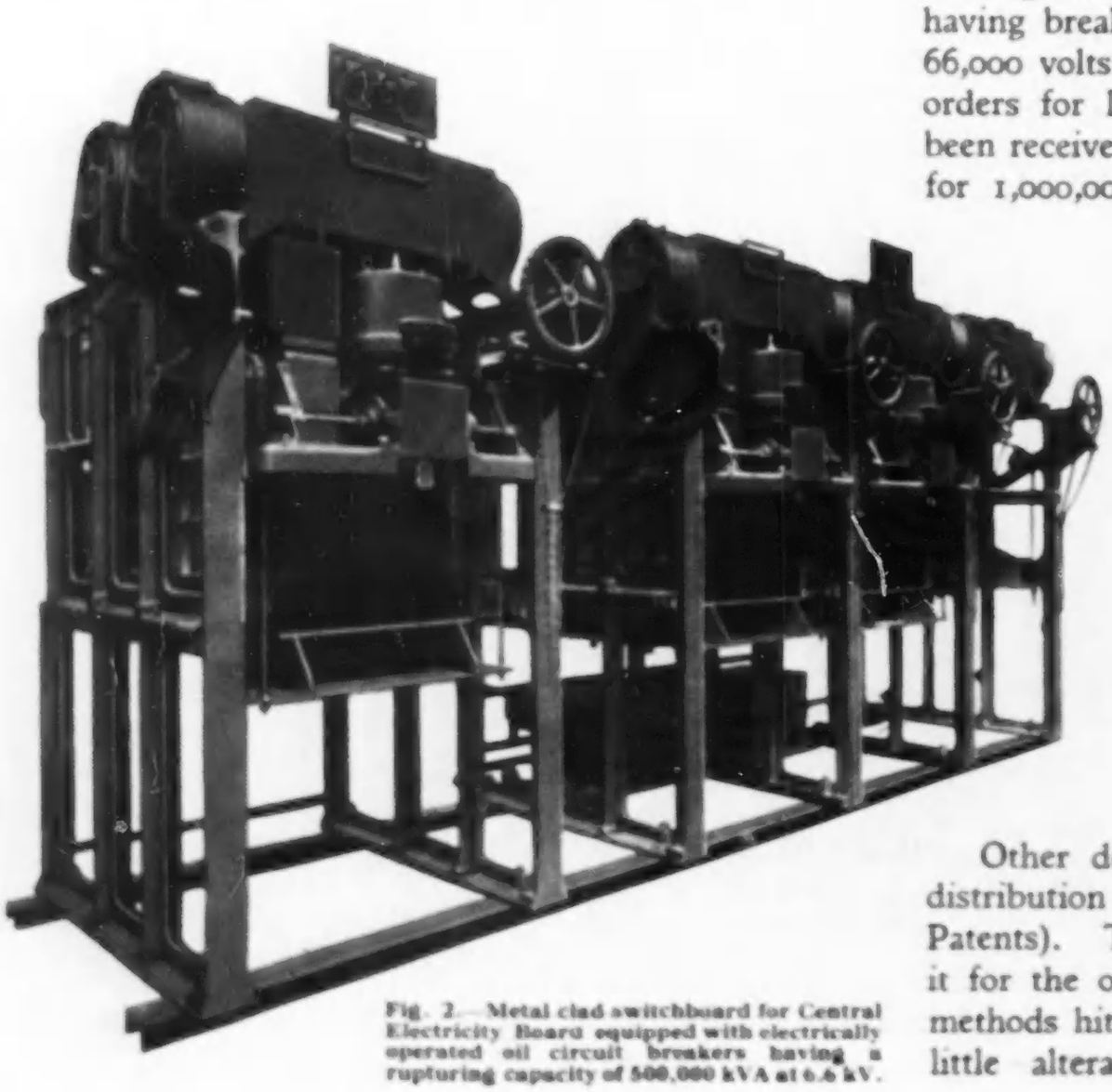


Fig. 2.—Metal clad switchboard for Central Electricity Board equipped with electrically operated oil circuit breakers having a rupturing capacity of 500,000 kVA at 6.6 kV.

SWITCHGEAR.

Some of the most important work in the realms of switch and control gear has been in connection with the "Grid," contracts for (1) overhead transmission lines for the Mid-East England Scheme; (2) switchgear equipment for the Central England Scheme and North West England Scheme, and (3) part of the transmission scheme from Hams Hall, Birmingham, to Ocker Hill. These are in addition to the contract placed during the previous year for transmission lines in South East England.

Fig. 3.—A commercial form of photo-electric cell.

A particular feature of interest in connection with the Grid switchgear is that when the first tender was submitted for the Scottish Grid a rotary type of isolating link was submitted by the G.E.C. This was adopted by the central Electricity Board as the standard form of link in all their schemes. The Grid outdoor type oil circuit breakers have a maximum breaking capacity of 1,500,000 kVA at a voltage of 132 kV. After an exhaustive study of the various methods of suppressing an arc effectively, four breaks per phase have been adopted to the exclusion of explosion pots.

Another direction in which marked progress has been made is in the development of metal clad switchgear, which is now available in standard sizes having breaking capacities up to 1,500,000 kVA at 66,000 volts and currents of 4,000 amps. Several orders for large capacity boards of this type have been received, one for the London Power Co. being for 1,000,000 kVA gear at 22,000 volts. This is required in connection with the Grid scheme, as is also somewhat similar 33,000 volt gear ordered by the North Metropolitan Electric Power Co. These are in addition to work in hand for several Corporations for this class of switchgear.

The demand for other standard types of switchgear continues, as is evidenced by one order for Cambridge Electricity Works and Sub-stations, consisting of fifty-eight 11,000 volt trucks and thirty-two similar trucks for Pretoria Municipality.

Other developments of note in connection with distribution relate to protective gear (McColl Patents). This has been suitably modified to fit it for the overhead lines at 132 kV, although the methods hitherto employed rendered necessary very little alteration to the standard types. Much

more stringent tests however have been carried out to make certain of the stability of the system, and these have confirmed that the standard apparatus is capable of complying fully with the more exacting requirements laid down.

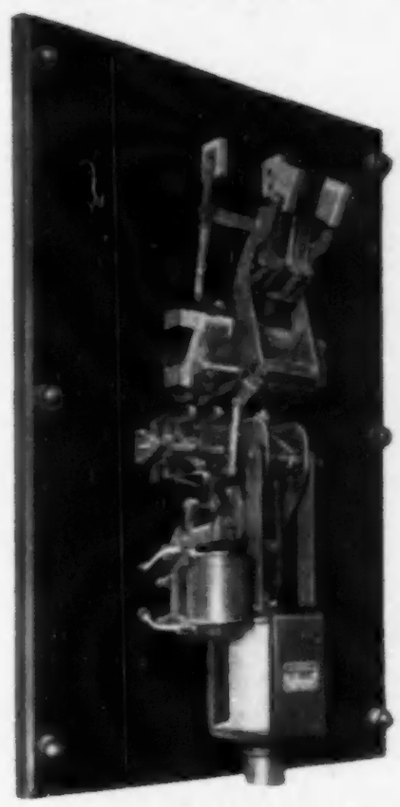


Fig. 4.—Line contact circuit breaker.

The protection of parallel interconnectors has been rendered more reliable and more sensitive by the use of the new biassed directional relay which has been applied to a number of lines; in one case step up and step down transformers were included in each of the feeders with satisfactory results. An article bearing on the protection of parallel interconnectors will be found on page 42 of this issue. Protective gear with a sensitiveness of 4 per cent. has been applied to the large 37,500 kVA turbo-alternators at Hams Hall Power Station, Birmingham.

Fig. 6.—44,000 volt outdoor switchgear at the Osborne Power Station of the Adelaide Electric Supply Co.

The development of the new "half-ratio" scheme has enabled bar type current transformers to be applied to these turbos and also to feeders, almost

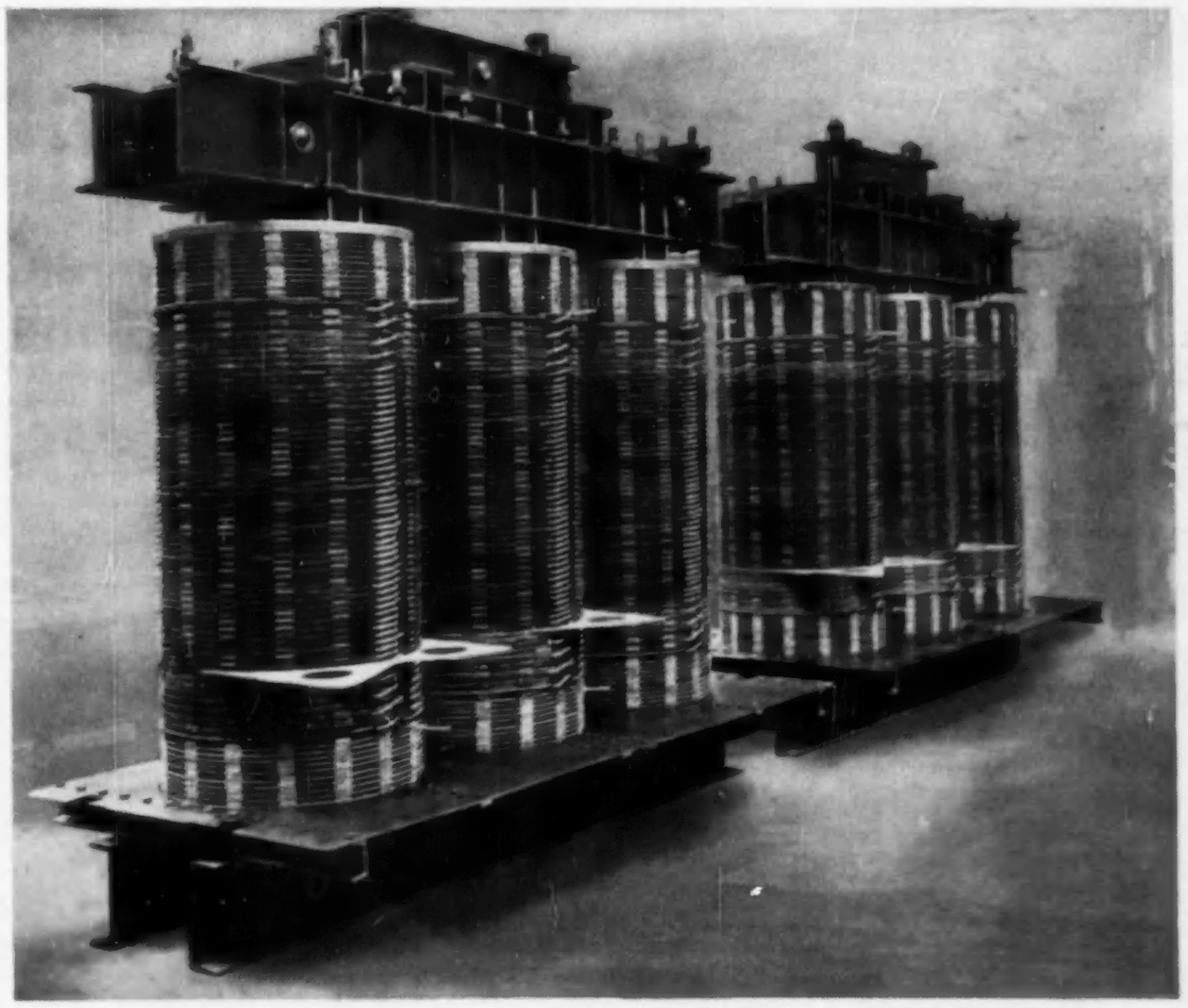


Fig. 5.—Two of several 3,750 kVA forced oil cooled transformers, 60,000/22,000 volts, in course of construction for export.

irrespective of primary current and in spite of the very small value of VA available. In the smaller capacities this is as low as 0.8 VA.

The range of automatic control gear available has been enlarged by the introduction of two lines of small mass-produced automatic starters for motors up to 3 h.p. and 5 h.p. respectively. These are very serviceable pieces of apparatus each including two contactors giving automatic acceleration on the counter E.M.F. principle.

Great developments have been made in connection with automatic control for apparatus in ships. The contactors and relays for this class of equipment have shown steadily improved characteristics during the year, a feature being the continued development of the shunt lock out contactor for the rapid acceleration necessary in marine work.

The "Line Contact" circuit breaker is another recent introduction. Its construction is on novel lines. Full advantage is taken of the self-aligning property of "V" edged blades bedding in grooves. A standard size of blade has been determined and by using any number of these blades, circuit breakers up to 20,000 amperes can be constructed with the utmost ease. After much experimental work the angle of the "V" groove was so chosen as to double the effective contact pressure previously obtained. When fully closed each blade is brought into contact by its own control spring with a force of 28 lbs. per blade. The length of blade in contact with each block is 1 in. so that the working pressures are 14 lbs. per inch of line contact. Each blade is made to deal with 125 amperes, and at this current the drop between the contact blocks is 8 millivolts of which 2 millivolts are in the blade itself, the remainder representing the contact drop.

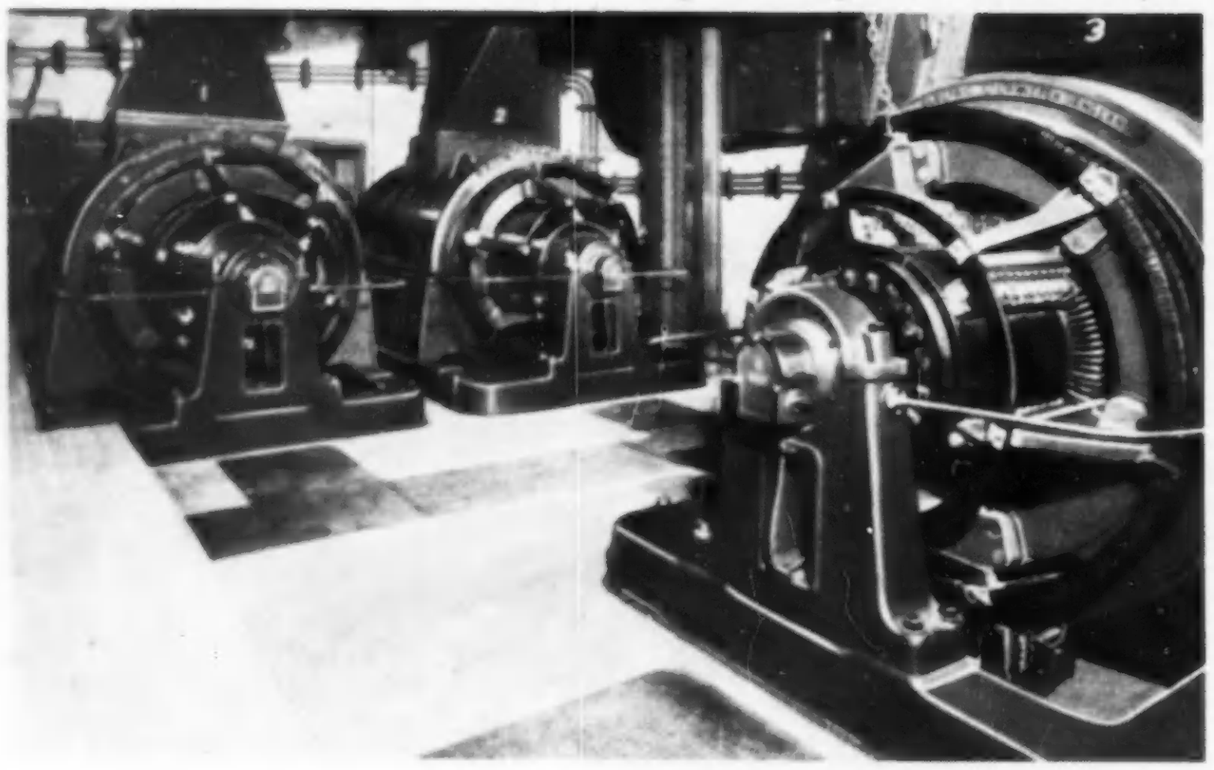


Fig. 7.—Three 750 kW automatic motor converters at Trafalgar Square sub-station, 11,000 volts. A.C. 3-phase. 50 cycles, 600 volts. D.C. 500 r.p.m.

By a most ingenious feature of design, not only are the contacts self-aligning but they are self-cleaning, as during the process of closing the breaker a vertical sliding action is transmitted to the blade, so that each surface is effectively cleaned at every operation of the breaker. The auxiliary metal contacts are designed to maintain their pressure even under short circuit conditions, until the blade contacts are well clear of the top block. The auxiliary carbon blocks and arc-breaking devices give sure and rapid breaking under the heaviest short circuit conditions.

There is an increasing demand for the high speed circuit breaker which is now available at prices considerably lower than those ruling a few years ago. Originally used in connection with railway electrification schemes, it is now being employed on tramways and light railways. Models have been continuously developed and now attain a very high degree of efficiency, a large number of 2,000 amp. 600 volt breakers being manufactured at the present time to meet demands.

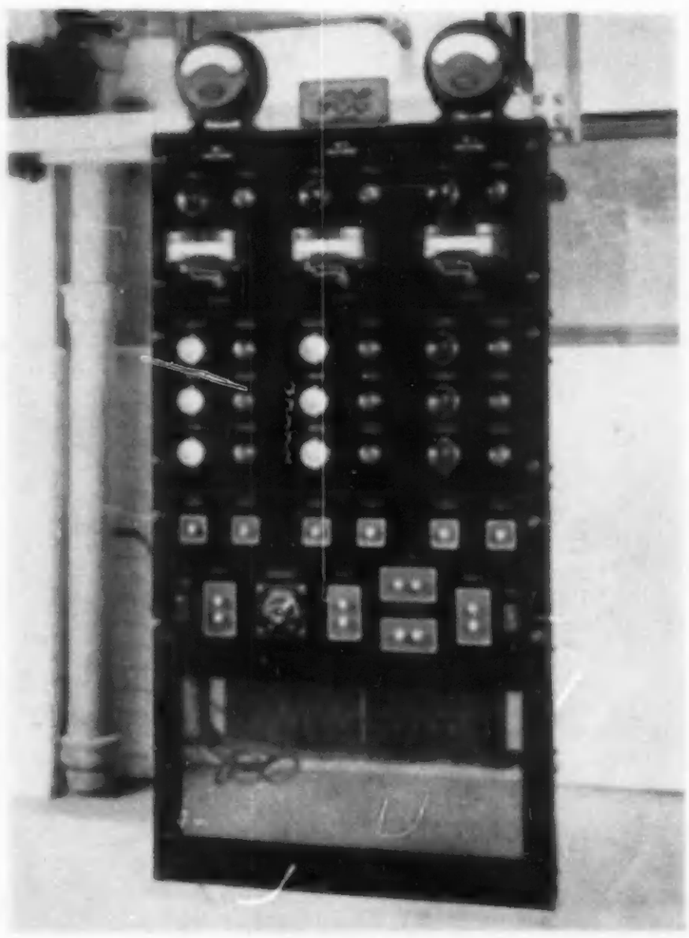


Fig. 8.—Remote control board at St. Martin's Lane power station, London, controlling the three motor converters shown in Fig. 7.

POWER INSTALLATIONS.

Among installations embracing a wide range of plant and switchgear several important equipments have recently been completed. Prominent amongst these is that for the Hams Hall Power Station, Birmingham, which includes two 37,500 kVA turbo-alternators, D.C. house generators, high and low tension switchgear, transformers, motors, cables, and other equipment. The turbo-alternators are 1,500 r.p.m. machines, generating 3-phase, 25 cycle current at 11,000 volts.

Reference must also be made to the very comprehensive range of apparatus for Palestine including 7,500 kVA hydro-electric sets, power house switchgear, extra high tension outdoor sub-stations, transformers and other equipment, while similar gear has been completed and is in hand for New Zealand, one individual order being for two 3-phase 16,500 kVA transformer banks, 110/66 kV (with one spare). These transformers are of the oil-immersed type fitted with detachable cooling radiators, and an unusual feature is the 11 kV tertiary winding which allows each bank to supply power to a 10,000 kVA synchronous condenser.

Two automatic 1,000 kW 750 r.p.m. motor started rotary converters are being constructed for the Auckland Electric Power Board, (each with its 1,100 kVA 3-phase transformer) together with fully automatic switchgear for the converters and four track feeders, the whole equipment being arranged for supervisory control if required. These rotary converters will be used for tramway traction supply.

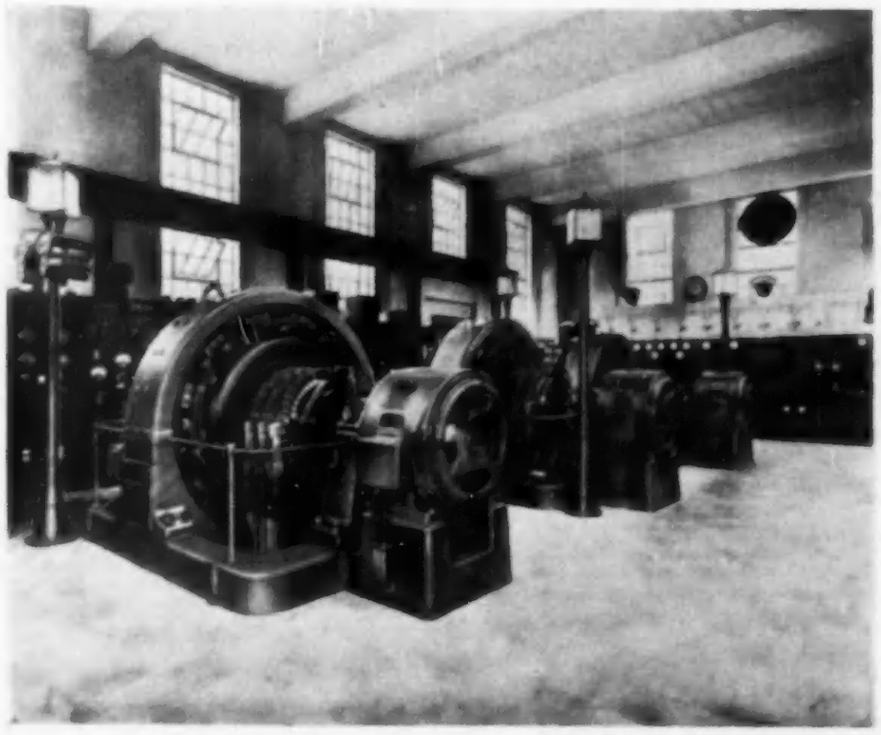


Fig. 9.—Three 2,000 kW rotary converters at Bermondsey main sub-station.

A contract for a prominent Australian mining company includes two 6,250 kVA turbo-alternators, two electric winding equipments (one of 1,500/2,200 h.p. being upon the Ward Leonard principle) and a most comprehensive range of mining plant, together with motors of a total capacity of over 4,000 h.p., main and auxiliary switchgear, etc.

Fig. 10.—1,500 h.p. Induction motor driving plate rolling mill through gearing, 3,300 volts, 3-phase, 50 cycles, 592 r.p.m.

For a Johannesburg mine a 1,500 h.p. 3-phase winding motor is in course of construction; and for the same town an automatic rotary converter sub-station has just been completed. A further South African contract includes a large quantity of mining plant for a copper mine together with two 1,000 h.p. synchronous induction motors, several smaller motors, and also switch and control gear.

TURBINES.

Some interesting developments in design have been effected in large steam turbines.

A machine of the two casing double pass-out type, (for a paper mill in Kent) which is believed to be the largest of the kind in this country, has a capacity of 10,000 kW. In a paper mill very fine regulation of process steam at a constant pressure is required. The pass-out gear which achieves this is interconnected with the main throttle and the turbine speed remains unaffected by fluctuations of steam extracted. The turbine operates with steam at a pressure of 290 lbs. per sq. in. and is arranged for two pass-out points, the first at a pressure of 105 lbs. per sq. in. and the second at 18 to 20 lbs. per sq. in.

A turbine of 30,000 kW capacity, having a speed of 3,000 r.p.m., is also under construction.

MATERIALS HANDLING EQUIPMENT.

Considerable activity in the production of coke for domestic and industrial purposes during the past year has resulted in a greatly increased volume of business in the manufacture of screens, coke cutters and conveyors for use in this industry. Gas works, coke oven plants and low temperature carbonization plants have all contributed to an increased output of this commodity. Coke is the

most difficult of all materials to handle in bulk form, chiefly due to its extremely abrasive nature and brittleness. A handling plant including a complete range of screens and grizzlies, has been developed which is eminently suitable for the work. A grizzly having adjustable discs has proved very suitable in circumstances where different sizes of product are required. Specially selected material is used for the discs and screening machines, and special precautions are taken to protect bearings and vulnerable parts from coke dust. These screens show a much higher capacity and efficiency than the older trommel type screen. The use of belt conveyors has also been considerably extended in this industry.

In the new Bussey Carbonisation Plant at Glenboig, an interesting feature is the automatic method of working, with entire elimination of manhandling of coal from the time of its delivery in wagons, which are unloaded by a tippler, to its discharge into retorts. Wagon tipplers, belt conveyors, skip hoists, push plate and tray conveyors, and drag scraper equipment are used to achieve this.

The activity in road making has again created a demand for machinery for crushing, grading and loading blast furnace slag.

Pennsylvania hammer crushers have been successfully introduced for crushing wet coal. Machines are being manufactured for dealing with coal having

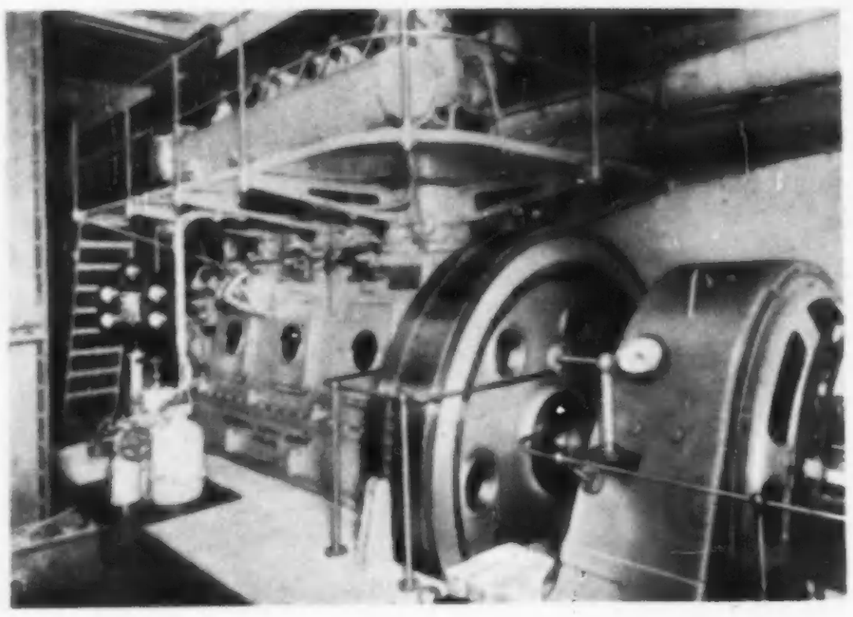


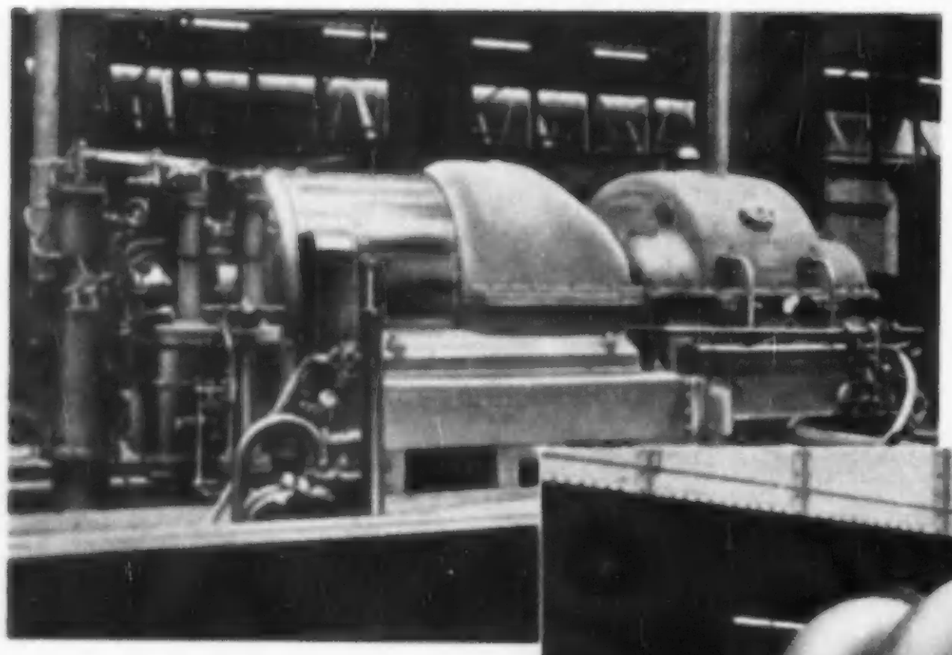
Fig. 13—875 h.p. Heavy oil engine driving 575 kW d.c. generator.

up to 12 per cent. moisture although a higher moisture content now presents no difficulties.

By arrangement with the Nordberg Mfg. Co., U.S.A., a number of the Symons Patent Cone Crushers have been manufactured during the past year. This is an entirely new machine of the cone type and incorporates many improvements. It is capable of an exceptionally high ratio of reduction, such figures as 14in. to ½in., 11in. to ⅜in., 8½in. to ¼in., 4½in. to $\frac{3}{16}$in., and 3in. to ⅛in., being achieved in one operation. Horse power per ton is exceptionally low and capacities cover a wide range from 7 tons to 900 tons per hour.

ELECTRIC TRACTION.

During the year there has been in course of construction at Witton Engineering Works equipment for two 350 h.p. Diesel-electric Locomotives for the Indian State Railways, North Western Section. These are described in detail in this issue.



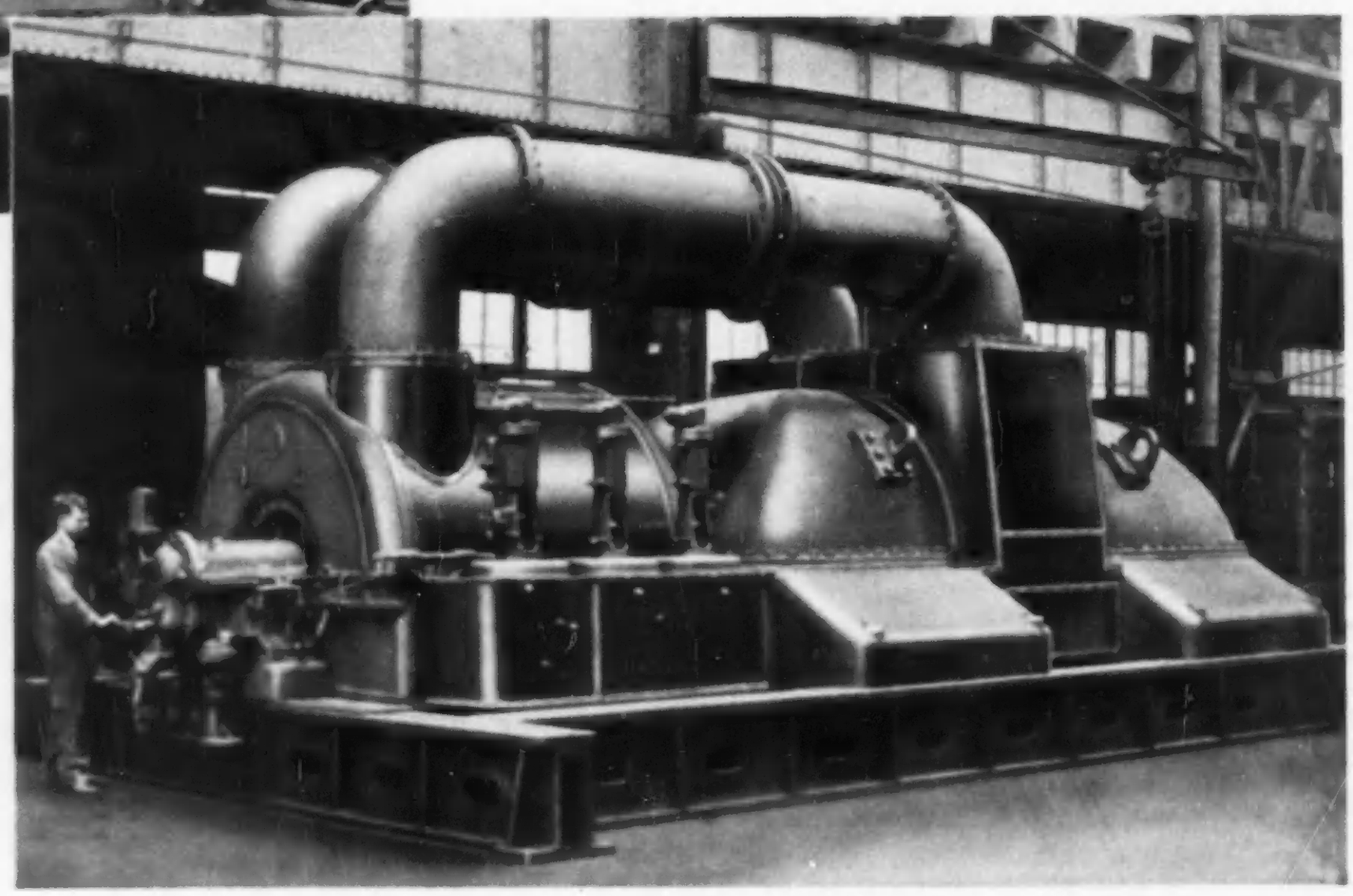


Fig. 11 (above).—3,500 kW Geared pass-out turbine for a Paper Mills, 3,600 r.p.m.

Fig. 12 (right).—30,000 kW High pressure turbine for Battersea, 3,000 r.p.m. Both views are taken in the test pit.

A very interesting traction development is the 1,500 volt equipment for the Manchester-Altrincham line, which is owned jointly by the L.M.S. and L.N.E. Railways. The equipment includes 100 heavy railway motors, each rated at 328 b.h.p. on the one hour rating, together with electro-pneumatic contactor type control equipments for 24 motor coaches, 22 trailer coaches, and 22 driving trailer coaches. It is noteworthy that this is the first order placed in this country by the Home Railways for equipment for trains operating on a 1,500 volt system, which is the standard fixed by the Ministry of Transport Committee. Previous to the Ministry of Transport's report the Newport Shildon line was in operation at 1,500 volts, but this is purely a mineral line, and the traffic is handled exclusively by locomotives.

A contract of importance is for a new Tube Railway, the Buenos Aires Central Terminal. This includes 56 sets of electrical equipment for motor coaches, each comprising two 105 h.p. motors with the necessary undercar electro-pneumatic contactor type control gear, also lighting equipment, cabling, conduit, etc.

Apart from these activities of outstanding interest, the manufacture of standard tramway motors and control equipments has proceeded on a large scale. One order covered over one hundred motors for Auckland, New Zealand.

MARINE ELECTRIFICATION.

Among the various marine electrification schemes in hand, that for a cement carrying vessel for the Canadian Lakes is especially interesting. The main feature of this is that electrical propulsion is being employed, the main driving motor of 775 h.p. being supplied with current from two Diesel driven D.C. generators rated at 360 kW, 440 volts, 220 r.p.m. The motor is of the double armature type, the mid point being earthed when in service. It is direct coupled to the propellor shaft and runs at a speed of 100 r.p.m., control being on the Ward-Leonard principle. The remainder of the electrical equipment is for emergency services, engine room auxiliaries, cargo handling main compressors, and other apparatus.

ILLUMINATION.

There has been marked activity in the sphere of illuminating engineering and many important installations have been carried out.

Illuminating engineering now covers so wide a field that it becomes necessary to divide it into different categories, such as the lighting of (a) Public Buildings; (b) Places of Worship; (c) Cinemas and Theatres; (d) Hotels and Restaurants; (e) Shops and Stores; (f) Banks and Offices; (g) Factories and Workshops; (h) Mines, Docks, Harbours and Aerodromes; (j) Railway and Transport undertakings; (k) Street lighting; (l) Flood-lighting; (m) Sports Grounds and Racecourses, and so forth.

This being the case it is only possible to refer briefly to a few installations of outstanding interest, some of which centre around the "Brighter London" movement exemplified by the new lighting of the Thames Embankment, Hammersmith Bridge, Portland Place, and other well known centres. The Thames Embankment, with its system of Wembley Street Lighting suspended above the roadway, is probably the finest example of street lighting in the world. The lighting is such that a newspaper can be read with ease at practically any point along this stretch of roadway.

Steady progress in the development of projector lamps has resulted in the production of a number of successful British films by means of gasfilled lamps for the first time in this country.

Fig. 14.—Lighting of the Thames Embankment—a view by night during the recent winter floods.

This is a field in which there has been very rapid development. Many sports centres are now illuminated by means of the dispersive system of lighting, while totalisators on several race courses have absorbed hundreds of thousands of lamps for signalling purposes.

The London Docks, with their newly designed system of dockside lighting stand as a typical example of illuminating progress, while Piccadilly Circus underground railway station lighting furnishes a further striking example in a different category. The same may be said of the new Underground Head Offices at St. James's Park.

The past year has also witnessed a significant advance in the lighting of cinema theatres,

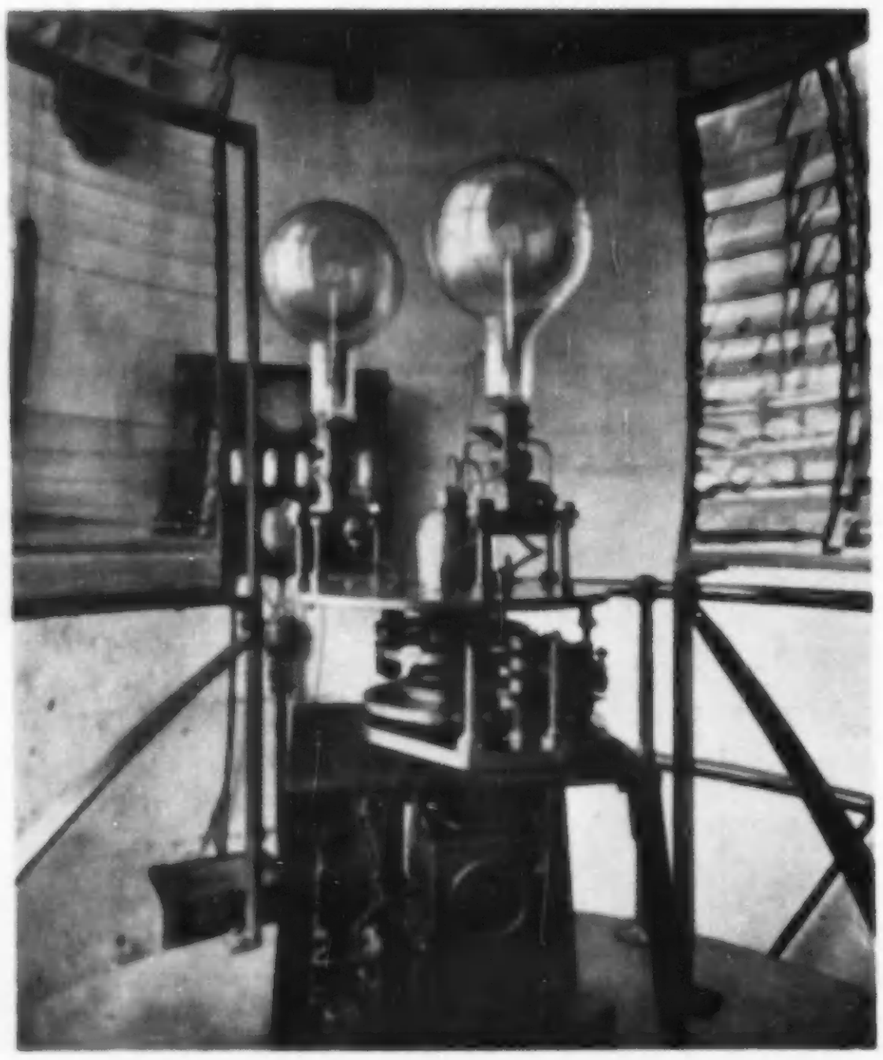


Fig. 15.—Large gasfilled lamps are now used in light-houses. This illustrates two 2 kW lamps in the "Low Light" at Burnham-on-Sea.

especially in the case of those that have adopted atmospheric lighting. Stage lighting in theatres and cinemas has made equally great headway, the new "Commodore" at Hammersmith being equipped with possibly the most modern stage lighting apparatus in this country.

The improved lighting of public buildings is well exemplified in the new Pavilion at Bournemouth, the new Nottingham City Council Buildings, and the reconstructed Aquarium at Brighton. The flood-lighting of stained glass windows is likely to become popular since a move in this direction has been made by the City Corporation at the London Guildhall and by several City companies.

In church lighting, St. Martin's in the Fields, London, furnishes a fine example of the adaptation of existing lighting units, while the church of the "Holy Name" at Manchester, with its silhouette flood-lighting scheme strikes an entirely new note. Progress has also been made in the artistic lighting of gardens, pleasure grounds, seaside promenades and beaches; the Blackpool autumn illumination scheme this year transcended anything previously attempted in this country, nearly half a million lamps having been used.

The use of the colour corrected light furnished by the Daylight Blue Lamp for the purpose of securing decorative effects, or of improving acuity of vision, continues to increase. Notable examples, in widely diverse applications, are furnished by the effects secured at the Davis Cinema, Croydon, and the equally effective use of this system of illumination throughout the huge range of offices in the new headquarters of the Imperial Chemical Company.

ELECTRIC LAMPS.

Regarding new types of lamps, it is interesting to put on record that the chief progress during the year 1929 has been at the opposite ends of the scale of ratings. Considerable progress has been made in producing very small lamps with very low consumption, such as the neon indicator lamp, which measures only 55 mm. overall length by 18 mm. diameter, and consumes 0.5 watt. This lamp is of great value for use as an indicator to show whether circuits are connected or not, and to indicate in the dark the position of any object such as a switch.

Another small lamp that has been developed during 1929 is known as the pygmy sign and berth light lamp. This is an ordinary vacuum metal filament lamp with a spiral filament. Its chief feature is its very small size for a lamp for use on normal circuits from 100 to 260 volts. The lamp consumes 15 watts, and gives ample light for an illuminated sign or for a berth light, and is 62 mm. long by 33 mm. in diameter.

At the other end of the scale the development of the use of gasfilled lamps in film studios for the taking of pictures has necessitated the production of lamps of sizes which would have been deemed impossible a very few years ago.

In the taking of cinematograph films, each picture is exposed for only a very small part of a second. A very high intensity of illumination is therefore required to enable a good photograph to be obtained. Further, this intense light is required to be under very close control so as to ensure proper moulding and shading of the picture.

Special ranges of fittings have recently been developed, together with large gasfilled lamps for use with them. These lamps are designed to consume 2, 3, 5 or 10 kW, the largest (the 10 kW) being 596 mm. overall by 400 mm. diameter. They take something like 100 amperes under normal working conditions.

The technical improvements in the manufacture of projector type lamps, resulting from the development of a new treatment of the filament wire and of new methods of supporting it, have made possible a range of lamps for use in optical lanterns and other projection apparatus which is a great advance on anything previously available.

The result has been apparent in the increasing use of such lamps for advertising and many other purposes in which the projection of a powerful, concentrated beam of light is of importance.

Among special types of lamps which are not in ordinary use, attention has been given to the production of lamps used in making talking films, *i.e.* small lamps which are used for recording on a photographic film an image whose fluctuations are controlled by and represent graphically the sound which is going into the microphone, and which will eventually be reproduced by means of amplifier and loud speakers as used in the theatre.

The steady improvement in the sound reproduction of talking pictures is a proof that the problem is steadily being solved.

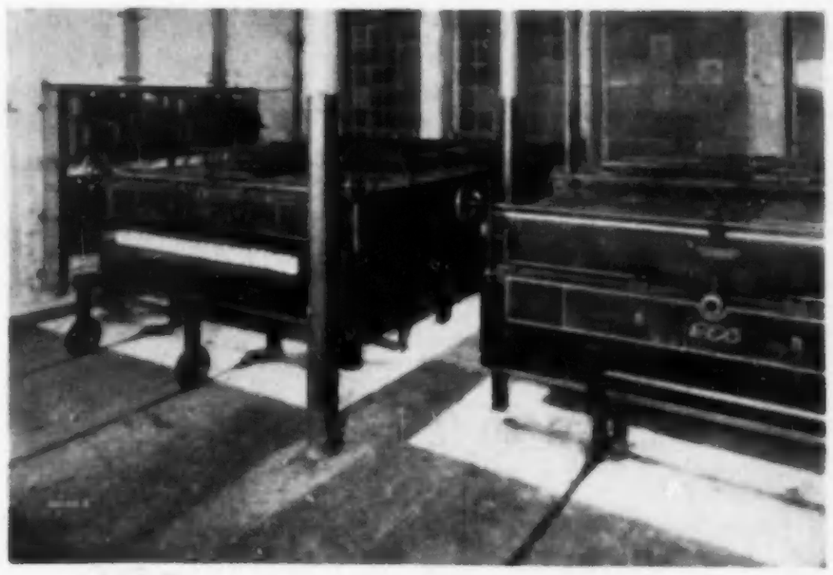


Fig 16.—Large electric drawplate baking ovens installed at Glasgow.

HOUSEHOLD APPLIANCES AND COOKERS.

Following the display at the Ideal Home Exhibition in March of last year of a range of domestic electric cookers of various sizes suitable for installation in any class of household, large contracts for cookers have been secured from supply undertakings and municipalities in England and the Dominions. A steady demand for a small type of cooker led in the early part of the year to the production of a neat and compact "breakfast cooker," and this has been found fully to meet such demand. Among the contracts obtained, one London Suburban authority purchased 200 cookers for an artisan housing estate. A new feature with regard to these household appliances and fires is that provision is now made for efficient earthing.

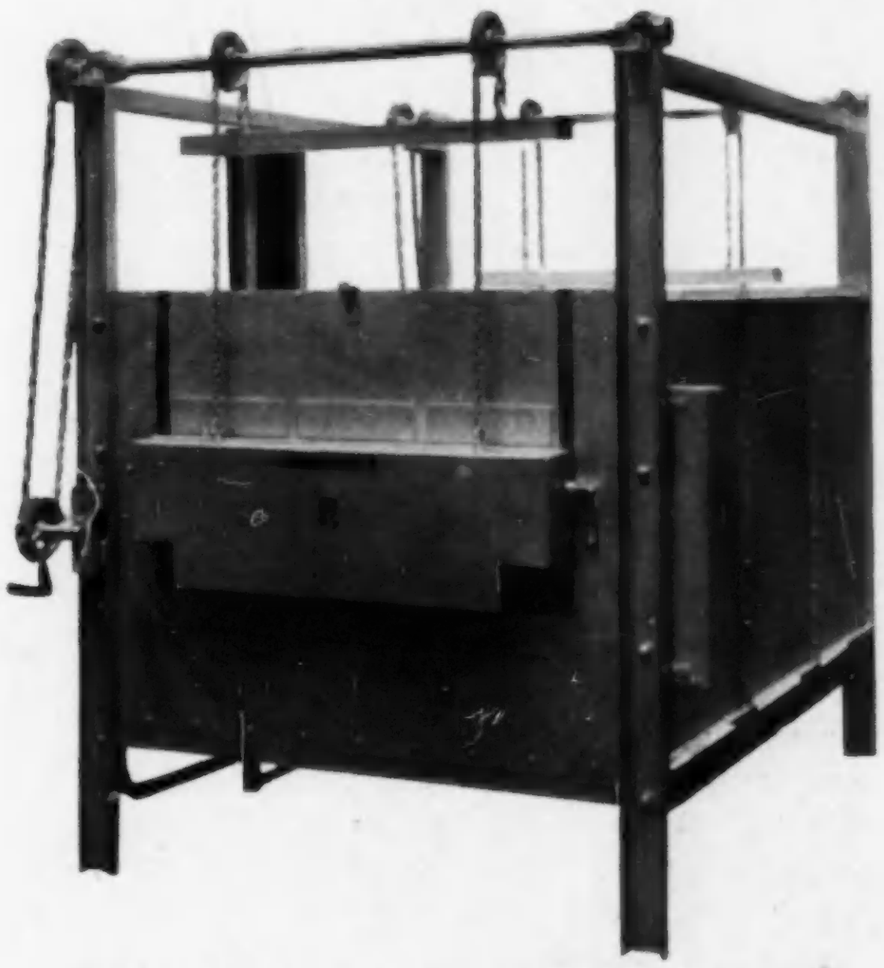


Fig. 17.—Electric furnace for annealing, and normalising brass stampings for motor car accessories.

INDUSTRIAL COOKING AND BAKING OVENS.

Reference should be made to the significant increase in installations of industrial cookers and baking ovens. These include hospitals, colleges, institutions and factories of a wide variety. Two drawplate baking ovens are in course of construction for a large firm of biscuit makers; they are believed to be the largest yet made, their principal dimensions being 15ft. by 8ft. 6ins.

ELECTRIC WATER HEATERS.

The rate of increase in the use of electricty is dependent to a considerable degree on improvement in central station load factors. The load which, more than any other, assists in this respect is water heating.

G.E.C. water heaters now range from 2 to 300 gallons in capacity, with loadings up to 50 kW and, being well lagged, are of very high thermal efficiency. Withdrawable type horizontal immersion heaters and patent quick make and break bi-metal thermostats are mounted in apparatus plates which are so constructed that they can be removed to expose hand holes for de-furring purposes.

So far as air heating is concerned—both industrial and domestic—a large number of installations has been completed, including in many cases thermostatic control within limits of plus or minus 1½° F. For such schemes, tubular heaters loaded to an average of sixty watts per foot are usually installed and during the year many thousands of feet of these heaters, up to 15 feet in length, have been used.

ELECTRIC FURNACES.

High temperature furnaces (1,000 to 1,350 degs. Cent.) have been developed for the heat treatment of high speed steel and some forging operations, while special furnaces have been made for the continuous annealing of austenitic steel strip and phosphor bronze wire. A satisfactory electric cupellation furnace is another interesting development.

Small metal melting pots and electric furnaces up to one ton hearth capacity for melting copper, aluminium, and other non-ferrous metals and alloys have also been included in the year's work.

Electric furnaces and ovens embodying mechanical features for the automatic progression of the work under treatment are now available to many trades and industries, as is also automatic temperature control gear capable of taking care of more or less elaborate heating programmes, with the result that labour requirements are either eliminated or considerably reduced.

WIRES AND CABLES.

The production of practically all types of wires and cables is on the increase. The Pirelli-General Cable Works at Southampton is now devoted solely to the manufacture of rubber insulated wires and cables, cotton covered wires, etc. By this arrangement the output of the works has been doubled. Other classes of cable work have been transferred to a new works at Eastleigh, where paper insulated cables and telephone cables are produced. The drawing and tinning of all copper wires is also undertaken at this new works.

Reference may be made to two important contracts (apart from the "Grid") during the period under review. The first, for the Egyptian Government, covers the manufacture of the cable and subsequent installation of a telephone trunk line between Alexandria and Cairo. The second includes v.i.r. cable and paper insulated lead sheathed ring main cables for six new torpedo destroyers for the Chilean Naval Commission.

High tension oil filled cable, which ranks among the most noteworthy developments of the century, is another product of these works.

RADIO RECEIVERS AND VALVES.

Progress is to be reported in several directions in the development and manufacture of radio apparatus. The trend in receiving sets is towards the mains driven type in which the power is derived from supply mains in lieu of the customary accumulators and batteries. A further development has been the introduction of sets which are entirely self-contained, incorporating provision for the current demands of the low tension and high tension sides of the sets, and an aerial and a loud speaker. These sets can also be connected to the supply mains by means of a plug for operation with an existing aerial and earth system and an independent loud speaker. Listeners who have no facilities for electrical power operation of sets, or who prefer the accumulator and battery as sources of current supply, have been catered for in an equally liberal way, and marked progress has also been made in this type of set in respect to sensitivity and selectivity.

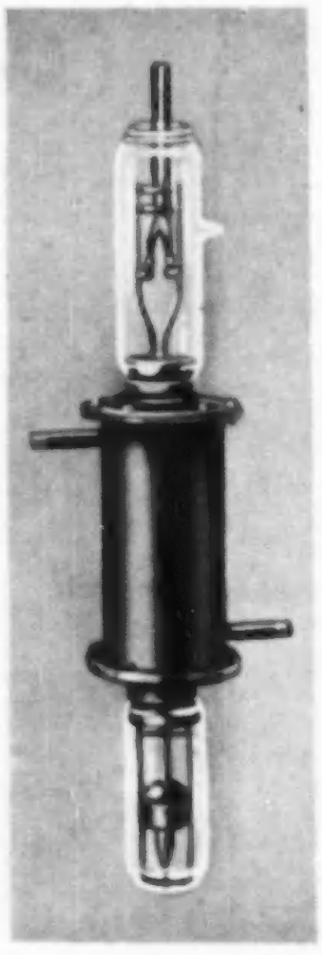


Fig. 18.—Typical short wave cooled anode transmitting valve.

The improvements effected in the characteristics of valves for broadcast purposes have also contributed to greater general efficiency in wireless reception. Not only have the filaments of these valves been strengthened and their emission appreciably increased, but the variety of valves has been considerably extended. Screen grid types for high frequency stages have been introduced for 2, 4 and 6 volt accumulators, and pentode valves are now also available for the same voltages. Valves for direct and indirect heating have also been evolved for each stage in multi-valve sets, and although they are called upon to function under somewhat strenuous conditions compared with their prototypes, their stability in structure and their electrical efficiency have already established them in firm favour.

High Temperature Resistance Alloys.

By S. V. WILLIAMS, B.Sc.
Research Laboratories of the General Electric Co., Ltd.

WITH the widespread use of electrical heating appliances the alloys employed in the form of wire and tape for the heating elements are becoming increasingly important. For some years alloys of nickel and chromium have been used for this purpose but very little information is available concerning their properties and relative value as high temperature alloys. Most of the available information on the subject has been published by the various manufacturers of nickel-chromium alloys and this, in general, applies to alloys containing 10 to 30 per cent. of chromium. In view therefore, of the importance of the problem, a comprehensive investigation of the subject was embarked upon at the Wembley Research Laboratories of the General Electric Company. The work has been proceeding for about three years and a preliminary survey of the field is given here. The results quoted are necessarily incomplete, but they indicate certain directions in which further research may usefully be continued. As a result of using very pure materials and carefully controlling the melting conditions, it has been possible to prepare and draw into wire nickel chromium alloys containing up to 50 per cent. of chromium, although commercially it is generally considered difficult to work binary alloys containing more than 20 per cent. of chromium. Certain of the ternary alloys containing nickel, chromium and either tungsten or molybdenum have given very promising results, particularly at higher temperatures.

The methods of test have been devised with the object of imitating as far as possible the conditions under which the alloys are used in practice. It is of interest to mention in this connection that the "life test" described later has found so much favour among makers of nickel-chromium alloys that it is likely to be adopted as a standard method of testing resistance-heater alloys.

PREPARATION AND WORKING OF AN EXPERIMENTAL SERIES OF ALLOYS.

Although commercial nickel-chromium alloys nearly all contain 15 to 20 per cent. of chromium it was decided to make as complete a range as could be worked into the form of wire. In addition, a number of ternary or three constituent alloys containing nickel, chromium and either tungsten or molybdenum were made.* In the first place it seemed desirable to make these alloys as pure as it is possible; melts were therefore made from specially purified materials.

Two grades of nickel were prepared for use in these experiments, one by the reduction of the oxide in pure hydrogen, the other by electrolysis. Spectroscopic examination showed the electrolytic nickel to be the purer of the two, and much purer than any commercial brand examined.

The electrolytic chromium was deposited from a pure chromic acid-chromic sulphate bath, and the degree of purity was very high, reaching 99.98 per cent. Cr. The alloys were made by melting 12 gram batches of the various compositions in refractory boats made from either magnesia or sillimanite heated in an alundum tube furnace capable of reaching temperatures up to 1,600° C. Nickel melts at 1,452° C. and chromium above 1,900° C., but a temperature of about 1,550° C. is sufficient to cause complete fusion of any alloy of the series. All the melting operations were carried out in a stream of pure hydrogen which prevented the alloy being contaminated with oxide. The use of very pure raw materials melted in pure hydrogen results, as will be shown later, in nickel chromium alloys which are better than those prepared in the ordinary way.† The compositions of the alloys prepared for the investigation are shown in Table I.

The first series up to and including No. 26, were made with reduced nickel and when preliminary tests on these had indicated which were likely to be the most useful, repeat melts were made with the electrolytic nickel. Subsequent tests showed that the slight difference in purity is important. It was generally believed that nickel chromium alloys containing more than 20 per cent. of chromium were practically unworkable and although there are a few commercial alloys containing about 30 per cent. of chromium they also contain a fair amount of iron in order to improve the ductility and general workability. As the result, however, of the care that was taken to

Much of the work on which this article is based has been published in greater detail in the Journal of the Institute of Metals (Laboratory Experiments on High Temperature Resistance Alloys, by C. J. Smithells and S. V. Williams, with an appendix on "The Electric Resistance of Nickel Chromium Alloys," by J. W. Avery, Journ. Inst. Metals, Vol. XL, No. 2. 1928), and some of the illustrations are reproduced from that paper by permission.

*British Patents 293728, 293740.—Improvements in the Manufacture of Electrical Resistance Elements.

†British Patent, 293727.—An Improved Process for the Manufacture of Alloys of Nickel and Chromium.

ensure extreme purity, no difficulty was experienced in working alloys containing as much as 40 per cent. of chromium into wire by cold rolling and drawing.

The alloy containing 50 per cent. of chromium was very hard and could only just be drawn cold, while the 60 per cent. chromium alloy was unworkable.

TABLE I—**Composition of Alloys.**

	Alloy No.	Chromium. %	Nickel. %	Tungsten. %	Molybdenum. %
Reduced nickel	9	10	90	..	..
	10	20	80	..	..
	11	30	70	..	..
	12	40	60	..	..
	14	50	50	..	..
	15	60	40	..	..
	16	10	85	5	..
	17	10	80	10	..
	18	10	70	20	..
	19	20	75	5	..
	20	20	70	10	..
	21	10	85	..	5
	22	10	80	..	10
	23	10	70	..	20
	24	20	75	..	5
	26	20	70	..	10
Electrolytic nickel	27 (10)	20	80	..	..
	30 (9)	10	90	..	..
	31 (11)	30	70	..	..
	32 (19)	20	75	5	..
	33 (26)	20	70	..	10
	34 (24)	20	75	..	5

MICROSTRUCTURE.

A few words on this point are probably of interest.

Up to 40 per cent. of chromium, the straight nickel-chromium alloys consist of a simple solid solution, that is to say, when viewed under the microscope, they show a structure similar to that of a pure metal, consisting of one crystalline phase only. With the 50 per cent. and 60 per cent. chromium alloys there are two crystalline phases present. This latter fact tallies with the difficulty experienced in working these two alloys, and with the fact that they are unsuitable for use as heat resistance wires. Fig. 1 is an example of the simple type of structure shown by the 20 per cent. chromium alloy, while fig. 2 shows the two phase structure of the 60 per cent. chromium, 40 per cent. nickel alloy in the cast state.

RESISTANCE TO OXIDATION.

The most important property of nickel-chromium and similar alloys from the point of view of their use in electrical heating appliances, is their resistance to oxidation. It was therefore necessary to find some reliable means for determining the relative resistance to oxidation of the different alloys.

Two methods had already been used for this purpose. In the first of these, the change in electrical resistance of a sample of wire is measured after various periods of heating at definite temperatures in air. This method is satisfactory, provided that the change in electrical resistance is entirely

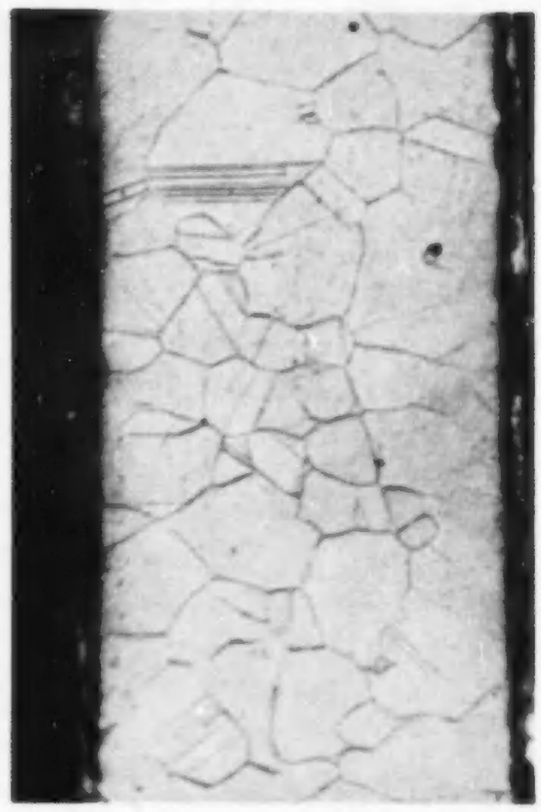


Fig. 1.—Section of 80 per cent. Ni, 20 per cent. Cr. alloy, showing simple structure.

due to oxidation and to the consequent reduction in the effective diameter of the wire. It will, however, be seen later that other factors such as mechanical and thermal treatments affect the electrical resistance of nickel chromium alloys. In some cases, also, oxidation does not proceed uniformly along the length of the wire so that the wire is left with a varying effective diameter, giving unreliable figures for the degree of oxidation when expressed in terms of the electrical resistance. For these

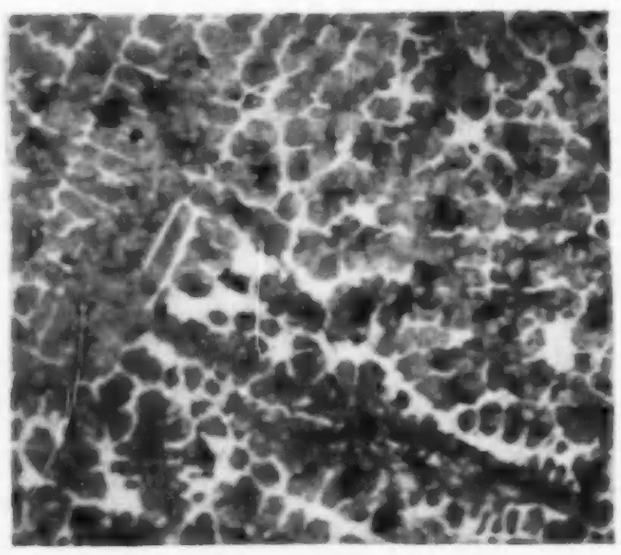


Fig. 2.—40 per cent. Ni, 60 per cent. Cr. As cast. Unetched. × 100.

reasons this method is not very satisfactory and was not adopted.

In the second method a sample of the wire is maintained at a constant temperature for various periods in a definite atmosphere of moist air or oxygen, the latter being used if it is wished to accelerate oxidation. Many wires were actually

tested in this way by heating short spirals to 1,000° C. in moist oxygen, the increase in weight being determined after various periods up to 10 hours. The results, however, were found to be completely at variance with the results of certain practical tests in heating appliances and with the results of other tests to be described later. Furthermore, certain alloys actually showed a decrease in weight although it was obvious that considerable oxidation had taken place. It was eventually found that this was due to the conversion of some of the chromium into sodium chromate, which was volatilised. This effect was most marked with the commercial nickel-chromium alloys, although it was obtained from all the alloys except those made from the purest materials. In any case it was sufficient to render the method of test quite unreliable.

LIFE TEST METHOD.

Apart from the objections already mentioned the above two methods have a further disadvantage, namely, that in neither is there any serious attempt to imitate the actual conditions under which the wires are used. With this last object in view the following procedure was finally adopted to obtain a rapid indication of the relative value of different alloys for use as heating elements. A sample of the wire is wound in the form of a short helix attached to the nickel leading-in wires of a lamp seal capable of carrying 10 amperes. The junction between the sample of wire under test and the nickel leading-in wires is made by pinching the end of the test wire in the bent end of the nickel leads, leaving about $\frac{1}{16}$ inch of the test-wire extending outside. This is then run up to the wire by means of an electric arc in an atmosphere composed of 80 per cent. nitrogen and 20 per cent. hydrogen. To operate at 900° to 1,000° C. such specimens require 8 to 9 volts. Fig. 3 is a diagram showing the mounting and dimensions of the specimens. In the first instance the specimens were enclosed in glass bulbs having an opening to the air, but the sodium chromate deposit, already mentioned, interfered with subsequent temperature measurements. It was then found that the glass bulbs could be dispensed with in the case of wires of 0.375 mm. and larger diameters. So long as the spirals were screened from direct draughts, consistent results could be obtained by running them unenclosed, and all the results given are for wires run horizontally in this manner.

TEMPERATURE MEASUREMENT.

The measurement of the temperature of a comparatively thin wire is not easy and, although a disappearing filament type of pyrometer can be used, it is not very suitable for a wire in the form of a spiral. The inside of such a spiral is always hotter than the outside, with the result that the actual temperature recorded is that of a particular spot on the wire rather than the average temperature of the whole. Further, since these pyrometers are usually calibrated against a black body a correction is necessary for the emissivity of the surface of the wire. In the case of oxidised nickel-chromium alloys this correction is relatively small and nearly the same for most wires of this type, but for bright drawn wires the correction is large and changes during the first half hour or so at 1,000° C.

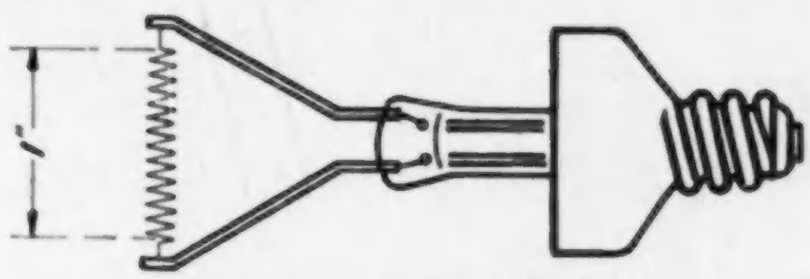


Fig. 3.—Standard dimensions of life test specimens.
Wire diameter, 0.375 mm. Pitch, $\frac{1}{16}$ in.
Mandrel diameter, $\frac{1}{8}$ in. Length of coil, 1 in.

The temperatures of the specimens were therefore measured by colour matching in a Lummer-Brodhun photometer head against the colour of the light from a standard carbon filament lamp. This lamp was standardised against a black body furnace, the temperature of which was in turn measured by means of a standard platinum, platinum-rhodium thermocouple. The procedure for setting up a specimen at any specified temperature was as follows. The standard carbon lamp was set to the desired colour temperature and the volts across the specimen adjusted until a match was obtained in the photometer head, the specimen then being set up on test at this voltage. A similar procedure was adopted for measuring the temperature of the specimen at any period during the test. It was found that readings could be repeated to plus or minus 10° C. at 1,000° C. and, provided the temperature of the specimen is uniform over its length, an average colour temperature very near to the true temperature is obtained.

This method of temperature measurement was further checked by spot welding the two wires of a very fine calibrated thermocouple to adjacent turns of a specimen. A very steady D.C. supply was used for heating the specimen, and the voltage across the couple measured with the supply alternately in both directions. The algebraic sum of these readings is twice the true thermal E.M.F. of the couple. Results obtained in this way were in close agreement with those obtained by colour matching.

AGEING.

Owing to the fact that with many alloys there is a considerable fall in temperature during the first few hours of the test, it was found advisable to give all test specimens a preliminary ageing for four hours at the temperature of the test. The

figure of four hours was arrived at after a consideration of curves connecting the fall in temperature of the specimen, when run on constant volts, with time. Some typical results are shown in fig. 4. It will be noted that the greatest drop in temperature occurs during the first two hours.

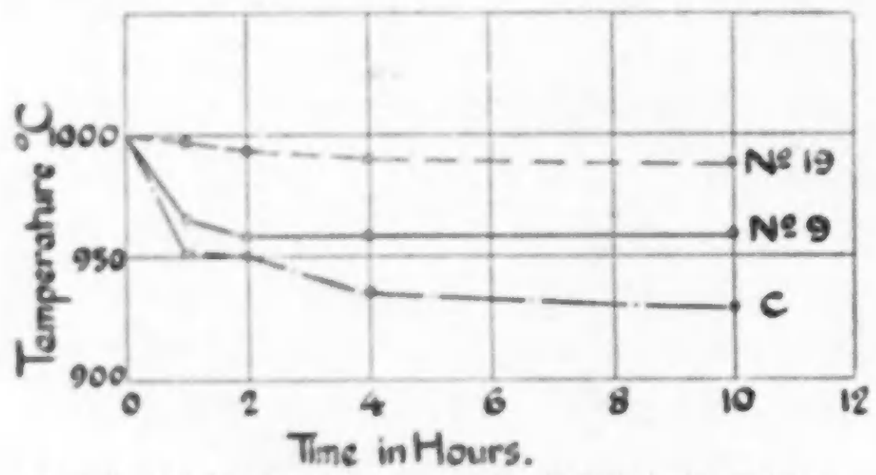


Fig. 4. Change in temperature of nickel-chromium alloy and wires during ageing on constant volts.

CONTINUOUS AND INTERMITTENT TESTS.

There was some evidence that with all electrical heating appliances the life is shorter on intermittent than on continuous tests. Specimen wires were, therefore, run under both conditions. With the "continuous tests" the current was switched off for one hour every twelve hours, whereas with the "intermittent tests" an automatic switch was incorporated in the circuit and set so that the current was switched on and off every two minutes. In the recorded lives on intermittent test both the on and off periods are included. In each case the results given are the average lives of three or more specimens of each alloy. The results of tests on the experimental alloys and a number of commercial alloys are summarised in Table II.

In considering the results of the tests, account must be taken of the fact that the temperatures of the various specimens fall by varying amounts during life. Thus while with some wires the temperature may fall only 10° or 20° C. during a period of 500 hours, in other cases it may fall 100° C. in 100 hours. This fall in temperature may result from increased resistance due to oxidation, or from sagging and distortion of the spiral which leads to excessive cooling by conduction and convection. Alloys which showed a fall in temperatures of more than 100° C. were neglected in assigning an order of merit.

Considering the results of the "continuous tests" at 1,100° C. it will be seen that there is a steady increase in life with increasing chromium content up to 30 per cent. of chromium. The sudden decrease in life shown by the 40 per cent. chromium alloy (No. 12) is probably connected with the difference already referred to in its crystalline structure. The 50 per cent. chromium alloy showed excessive sagging immediately it was put on test and for this reason the test was not carried to completion. Comparing the results for alloys, Nos. 9, 10 and 11, with Nos. 30, 27 and 31 respectively it is evident that there is a marked improvement in life as the result of using the slightly purer nickel in the preparation of the latter alloys.

The results for the ternary (or three constituent) alloys are interesting in so far as they indicate that there is a minimum percentage of chromium necessary for a satisfactory ternary alloy. For alloys Nos. 16 to 18 and Nos. 21 to 23, all of which contain 10 per cent. chromium with varying amounts of tungsten or molybdenum, the lives on the continuous test at 1,100°C. are actually shorter than for

TABLE II.

Result of Life Tests on Nickel-Chromium Alloys.

Alloy No.	Composition per cent.					Continuous test at 1,100°C.	Intermittent test at 1,100°C.	Intermittent test at 1,000°C.	Intermittent test at 900°C.
	Ni.	Cr.	W.	Mo.					
						Hours.	Hours.	Hours.	Hours.
9	90	10	—	—	—	120	—	—	—
•30	90	10	—	—	—	418	16	17	—
10	80	20	—	—	—	670	—	—	—
•27	80	20	—	—	—	830	46	180	—
11	70	30	—	—	—	720	—	—	—
•31	70	30	—	—	—	760	108	250	—
12	60	40	—	—	—	230†	—	—	—
16	85	10	5	—	—	27	—	—	—
17	80	10	10	—	—	44	—	—	—
18	70	10	20	—	—	35	—	—	—
19	75	20	5	—	—	403	—	—	—
•32	75	20	5	—	—	625	53	281	—
20	70	20	10	—	—	920	65	—	—
21	85	10	—	5	—	13	—	—	—
22	80	10	—	10	—	45	—	—	—
23	70	10	—	20	—	45	—	—	—
24	75	20	—	5	—	283	—	—	—
26	70	20	—	10	—	540	—	—	—
•33	70	20	—	10	—	800	153	440	—
Commercial Alloys	Nominal Composition Per Cent.								
	Ni.	Cr.	Fe.	Mo.	Mn.				
A	80	20	—	—	—	683	75	448	2845
B	80	20	—	—	—	552	53	229	2812
C	80	20	—	—	—	835†	53	462	—
D	60.5	15	20.5	—	4	—	28	116	823
E	61	15	18	4	2	—	45	190	> 2000
F	61	15	15	7	2	—	31	255	2233

* Indicate alloys made with electrolytic nickel.
† Tests not comparable on account of sagging.

the binary alloys (Nos. 9 or 30) which contain the same percentage of chromium. On increasing the chromium content to 20 per cent. and adding 5 or 10 per cent. of either tungsten or molybdenum (alloys 19, 20, 24 and 26) the lives so obtained compare favourably with those of the best binary alloys.

Comparing the results of "continuous" and "intermittent" tests, it will be seen that switching the current off at frequent intervals greatly reduces the life. This is because the protective oxide layer

Fig. 5.—Alloy showing protective type of oxide layer. Unetched. ×100.

becomes detached from the wire as the result of differential thermal expansion. For the majority of the alloys tested, the life on continuous test is about ten times the life on intermittent test, but for alloys 31 and 33 the difference is less marked. This indicates that the oxide layer is more adherent, and alloy 33 appears to be definitely the best of the experimental ones tested. This conclusion has been supported by tests with a number of domestic heating appliances. Table II also includes for some of the alloys results of intermittent tests at 1,000° C. and 900° C. As would be expected the life increases as the operating temperature is reduced although it will be noticed that alloy 30 containing 10 per cent. chromium is useless at 1,000° C. It would thus appear that there is a minimum chromium content necessary for a satisfactory nickel-chromium alloy.

OXIDATION PHENOMENA.

It is well known that the success of nickel-chromium alloys does not depend on the fact that they are not oxidised when heated in air but rather on the fact that the surface becomes coated with an oxide film which protects the metal from further oxidation. The results of the life tests on the various experimental alloys, however, indicated that a protective oxide film was not formed on all nickel-chromium alloys, so that it became necessary to investigate the nature of the film and the way in which it is affected by the composition of the alloy.

Microscopic examination of sections of wires of the various alloys after life tests showed that oxidation occurred in two different ways, and that the alloys could be divided into two broad classes on this basis. It was further found that this classi-

Fig. 6.—Same specimen as Fig. 5. Etched with $CuCl_2$ and aqua regia. ×100.

fication was in complete agreement with the result of life tests and showed a definite relation to the composition of the alloys. In the first, and desirable type, a thin film is formed on the surface of the wire and this film increases in thickness only very slowly. At a later stage the oxide begins to penetrate the grain boundaries and eventually extends right across the wire with the result that the resistance increases locally forming a hot spot which brings about failure of the wire.

Fig. 5 shows an unetched section of a wire with a thin surface film and grain boundary penetration just beginning, and fig. 6 shows the same section etched to bring out the grain boundaries and to make the nature of the penetration clearer. In the second type of oxidation the film, although often fairly adherent, appears to offer very little resistance to the penetration of oxygen, so that it rapidly increases in thickness, and eventually the whole of the wire is converted to oxide. Figs. 7 and 8 show a typical example of this type of oxidation at two magnifications. In fig. 7 the oxide has been broken off one half of the specimen.

In order to determine the nature of the different oxides, the oxides formed on the alloys

after heating for 10 hours at 1,000° C. in moist oxygen were subjected to X-ray analysis. It was found that three oxides may be formed on the surface of a nickel-chromium alloy, namely chromic oxide (Cr_2O_3) nickel oxide (NiO) and a compound of the two, nickel-chromite ($NiO.Cr_2O_3$). These three were present in the oxide films in all wires, but in different proportions. The nickel-chromite represents only a small proportion and can probably be neglected. The protective type of oxide contains a larger proportion of chromic oxide than the non-protective type; also the oxide scale which actually falls from a wire during life is found to be mainly nickel oxide. The oxide formed on the tungsten alloys contains an unknown compound probably of tungsten and nickel. The percentage composition of the various oxide films formed, estimated to the nearest 10 per cent., are given in Table III together with the nature of the oxide as seen under the microscope and the lives on continuous test at 1,100° C. for comparison.

Fig. 7.—Alloy showing non-protective type of oxide layer. Unetched. ×100.

Fig. 8.—Similar specimen to Fig. 7. ×500. (The unchanged metal is on the right.)

TABLE III.

Analysis of Oxides formed on Nickel-Chromium Alloys.

Alloy No.	Life on Continuous Test at 1,100° C. Hrs.	Type of Oxidation.	Approx. % Composition.		
			Cr_2O_3	NiO	Tungsten Compound
9	120	Protective	10	90	..
10	670		80	20	..
11	720		>90	<10	..
12	230		>90	<10	..
16	27	Non-protective	20	70	10
17	44		20	55	25
18	35		0	50	50
19	403	Protective	70	30	..
20	633		50	50	..
21	13	Non-protective	10	90	..
22	45		10	90	..
23	45		10	90	..
24	283	Protective	90	10	..
26	540		90	10	..

oxide. With 10 per cent. of chromium this is not the case but with 20 per cent. of chromium the protective type of oxide is obtained and it is probable that the minimum proportion of chromium necessary is about 15 per cent.

RESISTANCE TO SAG.

For many purposes for which nickel-chromium alloys are used it is important that the wire should not twist or sag under its own weight during life.

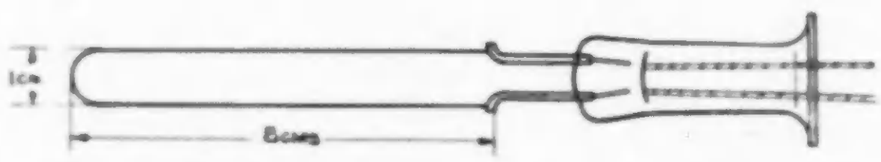


Fig. 9.—Standard dimensions of sag test specimens. Wire diameter, 0.375 mm. Time of heating, 1 hr.

This applies more particularly to those heating appliances in which the wire is only supported at intervals along its length. When dealing with heavier sections and correspondingly heavier loads, this property is known as creep and much work has been done on the determination of the limiting creep stresses of various metal at high temperatures. For the purpose of testing the resistance to sag

of the various nickel-chromium alloys, a standard test developed in connection with work on non-sag tungsten filaments was used because of the rapidity with which it can be carried out.

The standard sag specimen is shown in fig. 9, the hairpin of the wire under test being spot welded to the nickel lead-in wires of an ordinary lamp seal. Four such specimens were mounted horizontally and heated by suitable currents to 1,050°, 900°, 850° and 750° C. respectively. The current was switched off at the end of one hour, the inclination of the line joining the tip of the hairpin and the spot weld to the horizontal being taken as a measure of the sag at each particular temperature. For each alloy it is then possible to record the temperature at which the angle of sag equals some arbitrary value, say 15°.

In order to get more direct comparisons, specimens of each alloy tested at 1,050°, 900° and 750° C. respectively were photographed and the results are reproduced in fig. 11.

From this illustration, it will be seen that the resistance to sag of the binary alloys decreases steadily with increasing chromium content. It will be noted that the 50 per cent. chromium alloy sags more or less completely at 900° and 1,050° C. which appears to indicate that the second phase, previously mentioned, is particularly weak at these temperatures. The effect of the presence of impurities on the resistance to sag is seen by comparing the sag for alloys 9, 10 and 11 with that for the corresponding alloys 30, 27 and 31 made from electrolytic nickel. Similarly the commercial alloys A, B and C sag more than alloy 10 which has the same chromium content.

The ternary alloys, containing 20 per cent. of chromium, sag slightly more than the binary alloys having the same nickel content. The influence of impurities is again emphasised by comparing the results for alloys 19 and 26 with those for alloys 32 and 33 made from electrolytic nickel. This test, although very severe, gives a quick and easy method of comparing the relative resistance to sag of different alloys. Fig. 10 shows the sag of three life test specimens after 500 hours burning and the degree of sag is in close agreement with the results of the sag test as shown in fig. 11.

APPLICATION TO ACTUAL HEATER.

Fig. 12 illustrates the difference in behaviour between a standard commercial alloy and one of those made experimentally from pure materials (27). The two wires were used for winding two similar pedestal heaters, designed to run at a temperature of 750° C. These were put on test at 900° C., being run for half-an-hour on and half-an-hour off alternately. The illustration shows how the commercial alloy failed by sagging and short circuit after 120 burning hours (left hand photo-

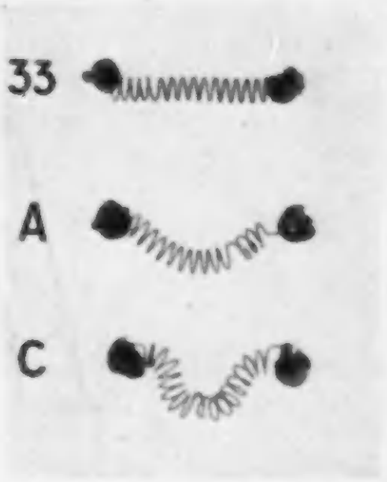


Fig. 10.—Life test specimens showing various degrees of sag after 500 hours at 1,100° C.

graph), while the experimental wire still retained its shape perfectly. Subsequently the experimental wire was run for a total of 800 hours before it distorted seriously. The two dark patches underneath are also interesting; they represent the amount of oxide found in each case in the bowl of the heater after test. The weights of these heaps of oxide were in the ratio 24 : 1.

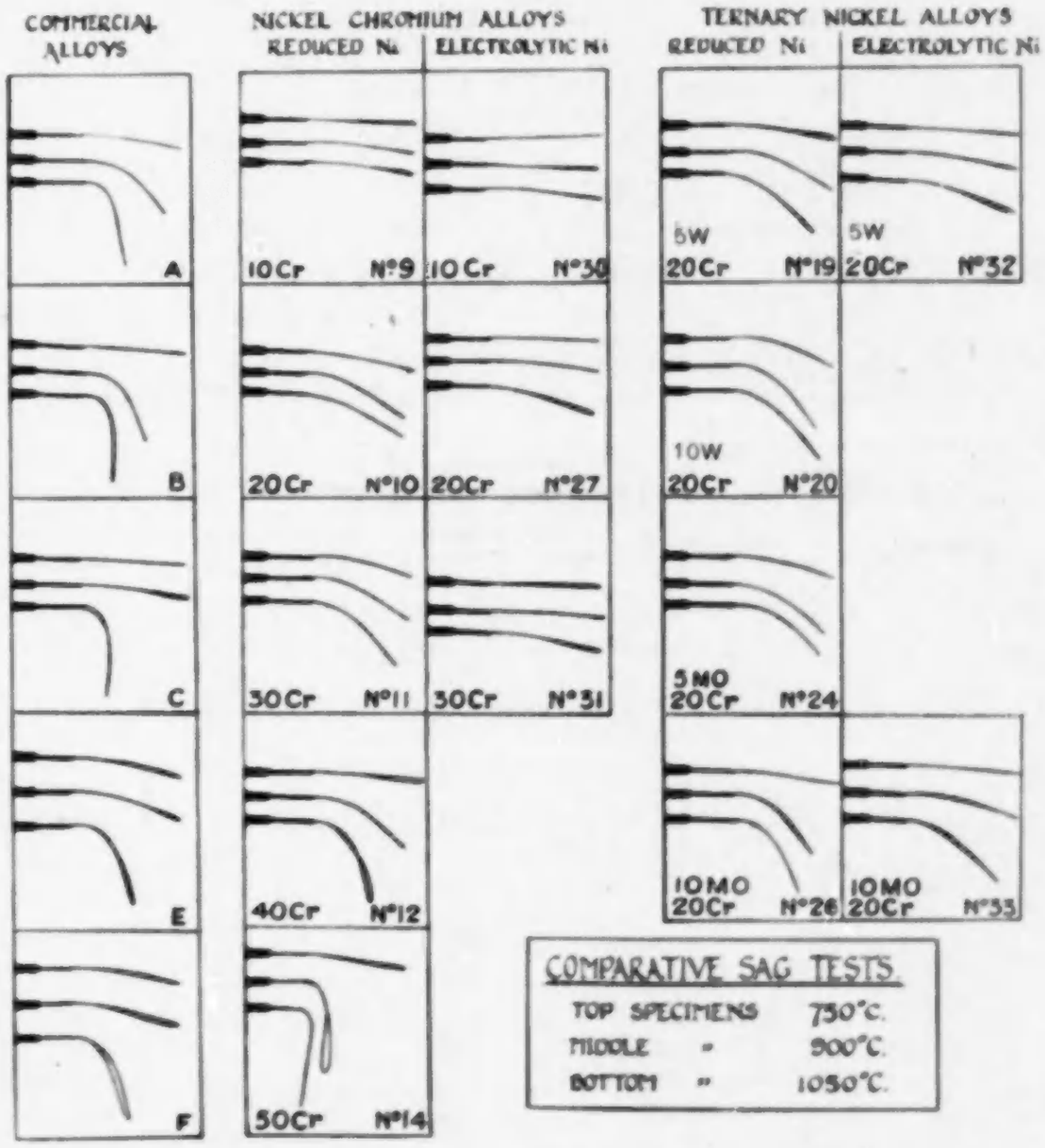


Fig. 11.—Comparative sag tests.

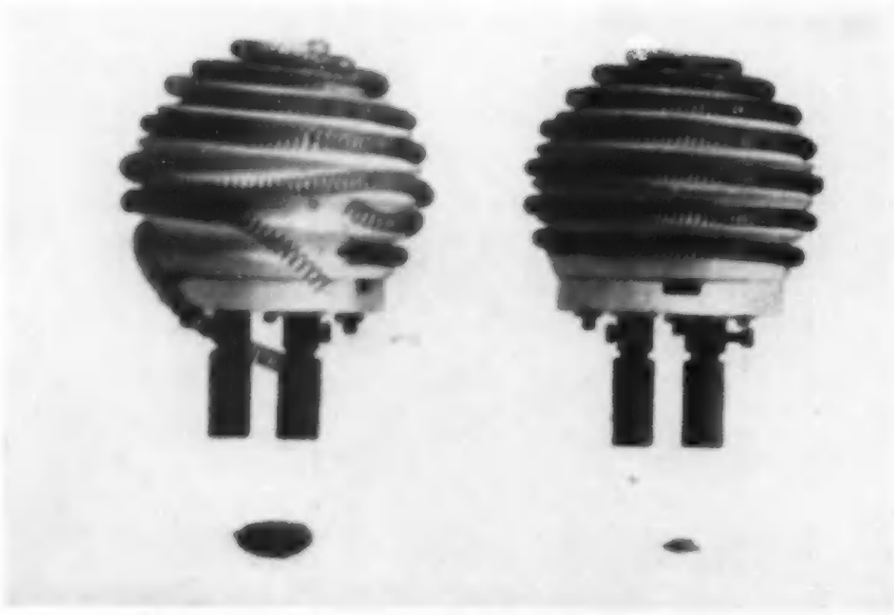


Fig. 12. Comparative tests of wires under working conditions on pedestal heaters.

ELECTRICAL PROPERTIES.

The resistivity of most of the alloys has been determined over the temperature range between room temperatures and 1,000° C. The specimen, bent into a hairpin, was mounted in a silica tube through which a stream of nitrogen was passed to prevent oxidation, and the whole heated in a furnace. The temperature of the specimen was measured by a thermocouple mounted beside it and the resistance was obtained from the voltage drop across a known length of the specimen when a measured current was passed through it. The specific resistance was finally calculated from the dimensions of the specimen. Measurements were taken during heating and cooling and it was found that some time was required to attain equilibrium, a complete cycle occupying about three hours. The readings taken during cooling in the second cycle, which appeared to represent a steady state, were used for the final calculations. The results are summarised in the curves given in fig. 13. These curves all belong to the same type and show a maximum or point of inflexion at 500° to 550° C. Alloy 14 (50 per cent. Ni, 50 per cent. Cr) which has been shown as not belonging to the same type, has a much greater temperature co-efficient. In general, the higher the chromium content the higher the resistivity at room temperature. The molybdenum alloys, have a higher resistivity than the corresponding tungsten alloys. The temperature co-efficient of resistance is less for the alloys of higher resistivity and generally becomes negative above 600°C. Alloys 23 and 26 have a slightly lower resistance at 1,000° C. than at room temperature, whilst alloys 19, 20 and 24 show practically no change in resistance between the two temperatures.

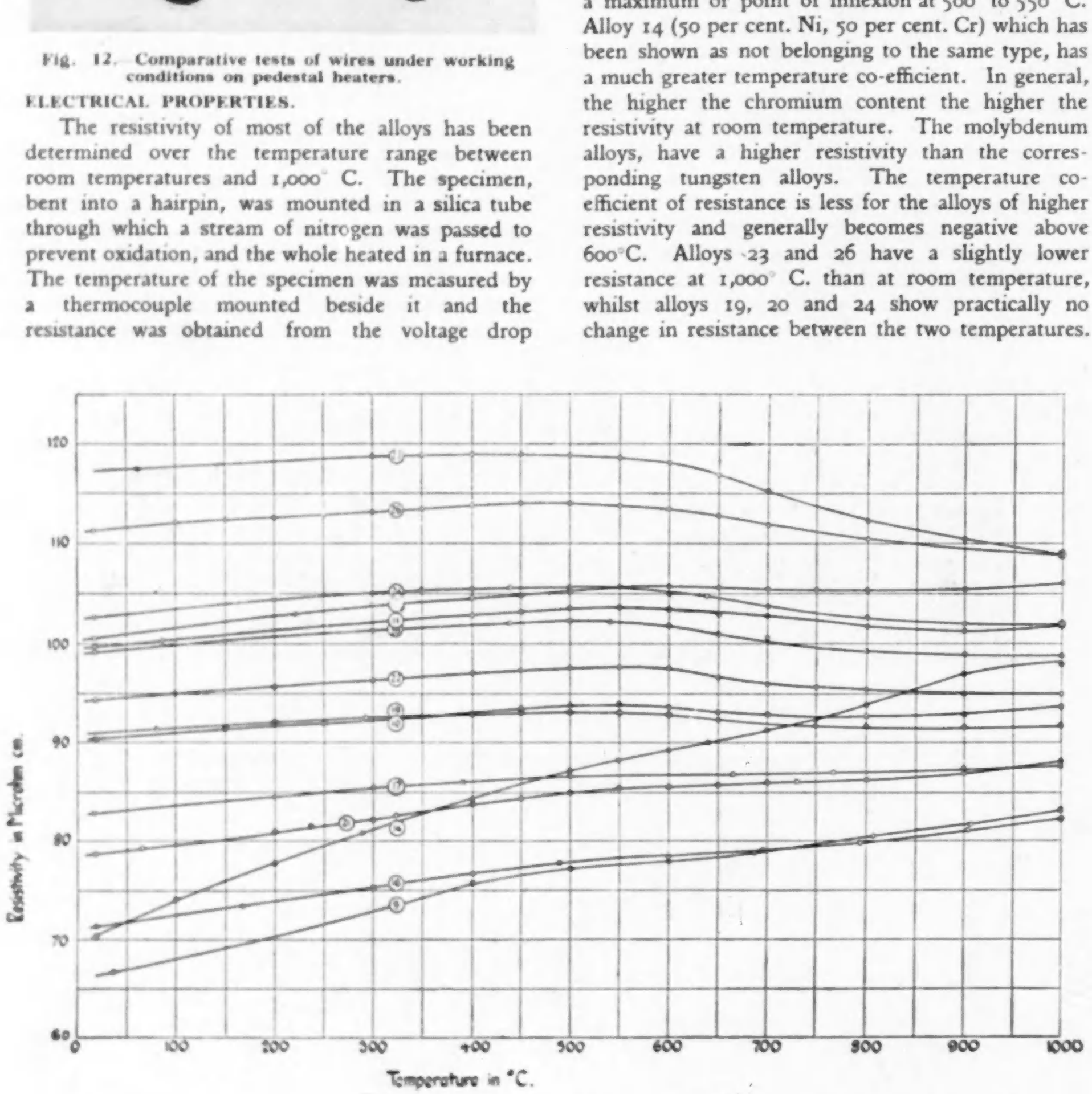


Fig. 13.—Resistivity-temperature curves for nickel-chromium alloys. Reference numbers correspond to the alloys in Table II.

Materials Handling Equipment for Modern Coke Ovens.

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DURING the past ten years steady progress has been maintained in the design of equipment for handling coal and coke for modern coke oven plants. It is therefore proposed in this article to describe a typical plant suitable for a battery of modern coke ovens having a capacity of, say, 1,200 tons per 24 hours.

This plant consists of the equipment for unloading the coal from the railway sidings upon its arrival, the necessary apparatus for the proper mixing and blending of different quantities of coal, the machinery for breaking and crushing the coal before delivery to the oven bunkers, and, on the coke side, the conveyors for receiving the coke from the coke wharf and the various appliances for screening and grading the coke into the various sizes required for the blast furnace and other uses. A general view of such a plant is shown in fig. 1, while the layout is illustrated in fig. 2.

Fig. 1.—Coal and coke handling and coke screening plant at the Consett Iron Co.'s Derwenthaugh Coke Works.

COAL PREPARATION AND HANDLING PLANT.

It is assumed that the coal will arrive at the site by rail, as the number of coke oven batteries which are placed close to the sea board and which receive the coal direct from ships or barges is very few.

In most cases the oven batteries are situated in close proximity to the pit head or to a number of pit heads, and it is very desirable that a number of modern self-dumping coal wagons of, say, 20 tons capacity be provided and employed for carrying the coal from the pit head to the coke oven plant. In this way all the apparatus for lifting and tipping trucks can be eliminated. Where this is not possible, a suitable truck tippler of the automatic self-clamping type should be installed, capable of discharging wagons at an average rate of 200 tons per hour. The side dumping type of wagon tippler necessitates the minimum amount of excavation work. It discharges the coal from the wagon several feet above ground level, thus reducing the cost of the receiving hoppers.

Where self-dumping wagons are used, the hoppers are placed below the wagon. In either case the hoppers should be provided with a grill or grid to remove extra large lumps of coal. Otherwise the whole system of receiving hoppers and conveyors up to the breaking and crushing plant would have to be large enough to handle lumps of coal of the maximum size. This would probably mean an unnecessarily large and expensive plant. With coal of average character, it is usual

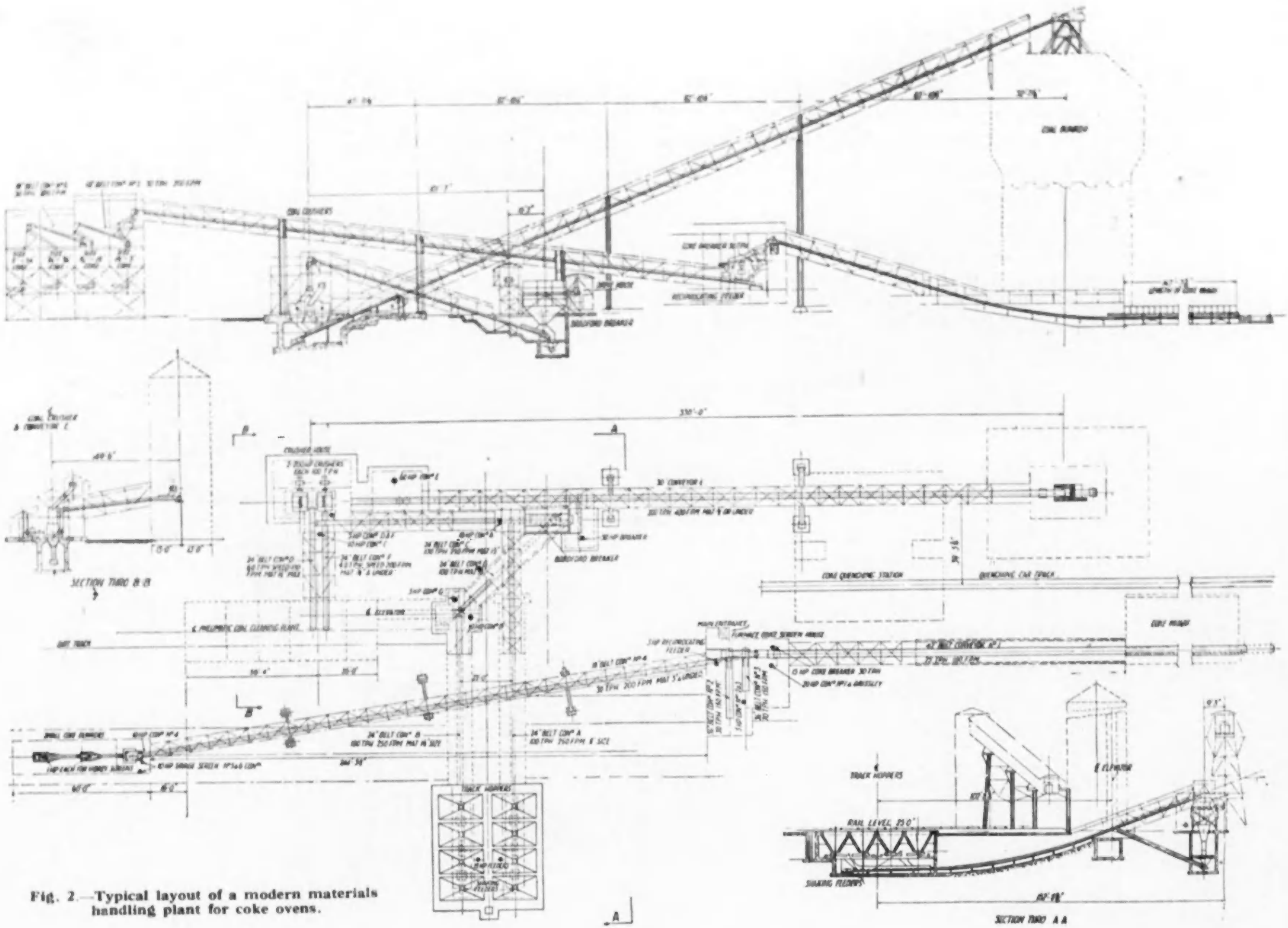

Fig. 2.—Typical layout of a modern materials handling plant for coke ovens.

to furnish a 6-in. grid over the hopper, the amount of coal which this would exclude being negligible. The larger lumps would be broken by hand.

Fig. 3 illustrates one of the latest types of truck tippler designed to discharge the contents of 12-ton wagons into a bin situated beside the tippler. The top of the bin is, approximately, 4 ft. above the top of the rails, thus obviating the necessity for a deep pit such as is required with the ordinary ring type tippler.

The tipping action is entirely automatic, and when in the tipped position, no clamping or binding devices are required for holding the wagon to the rails, thus decreasing the length of time required for the cycle of operations and proportionally increasing the capacity of the tippler.

The equipment consists essentially of four main parts, namely :—

(1) A rail frame or table upon which the wagon is placed.

Fig. 3.—Automatic truck tippler.

(2) A pair of lifting arms firmly attached at their upper ends to a built up steel trunnion, to the side or face of which is attached the lower bolster.

(3) A pair of rolling arms, complete with rolling path and upper bolster.

(4) A superstructure built above the machine for supporting the hoisting drums ; also an electric motor and gearing.

In its normal position the rail frame rests upon solid foundations so that the tippler and ropes are not stressed by through traffic.

The bearing pads are mounted on a steel plate which allows motion to take place between the pads and the trunnion. This motion is necessary when

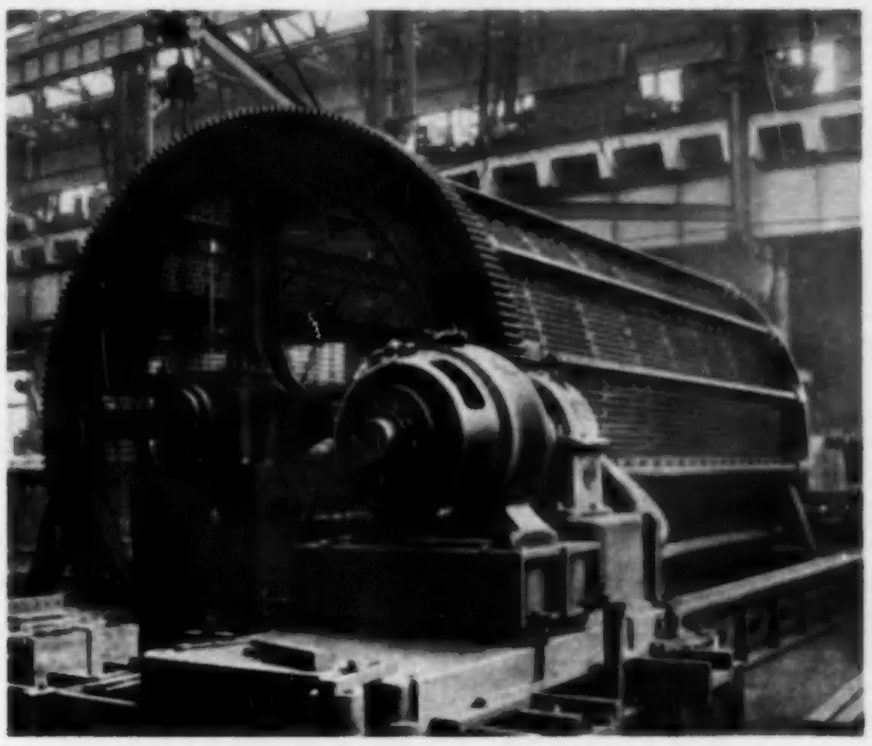

Fig. 4.—Pennsylvania Bradford coal breaker.

the springs of the wagon exert themselves as the load in the wagon is discharged and relieves wear to the pads and strain to the wagons.

The rolling arms are bored out at the lower ends to fit, and turn about the axial pins on the trunnion girder, while the face of the arms rests upon and gears with the roller path. Across the upper ends of the arms the top bolster is arranged as shown in fig. 3.

There is no positive connection between the lifting arms and foundations other than the pin connections at the lower end of the rolling arm. The trunnion girder is thus free to rise as the rolling arms roll forward.

ACTION OF THE TIPPLER.

The loaded wagon to be discharged is run on to the rail frame and the brakes applied. The electric hoisting gear is then started and, as soon as the lifting arms begin to rise, the rail frame and the wagon are gradually inclined over towards the bin, the action being controlled by the pivoted point and the cam shaped portion, working on the rollers supported on the foundations. This preliminary action is concluded when the side of the wagon comes into contact with, and rests upon, the lower bolster. The hoisting being continued, the wagon, rail frame and lifting arms form one unit and revolve about the trunnion pins, until the top of the wagon meets the top bolster attached to the rolling arms. All these now form a final unit, which, on continuing the wind, revolves and rolls along the rolling path until the load is fully discharged. The hoisting gear is then reversed and

the wagon brought back to the original position ready for removal and replacement.

The machine described can be designed to handle coal wagons up to 20 tons capacity and can be used without alteration to handle smaller trucks of normal design and construction.

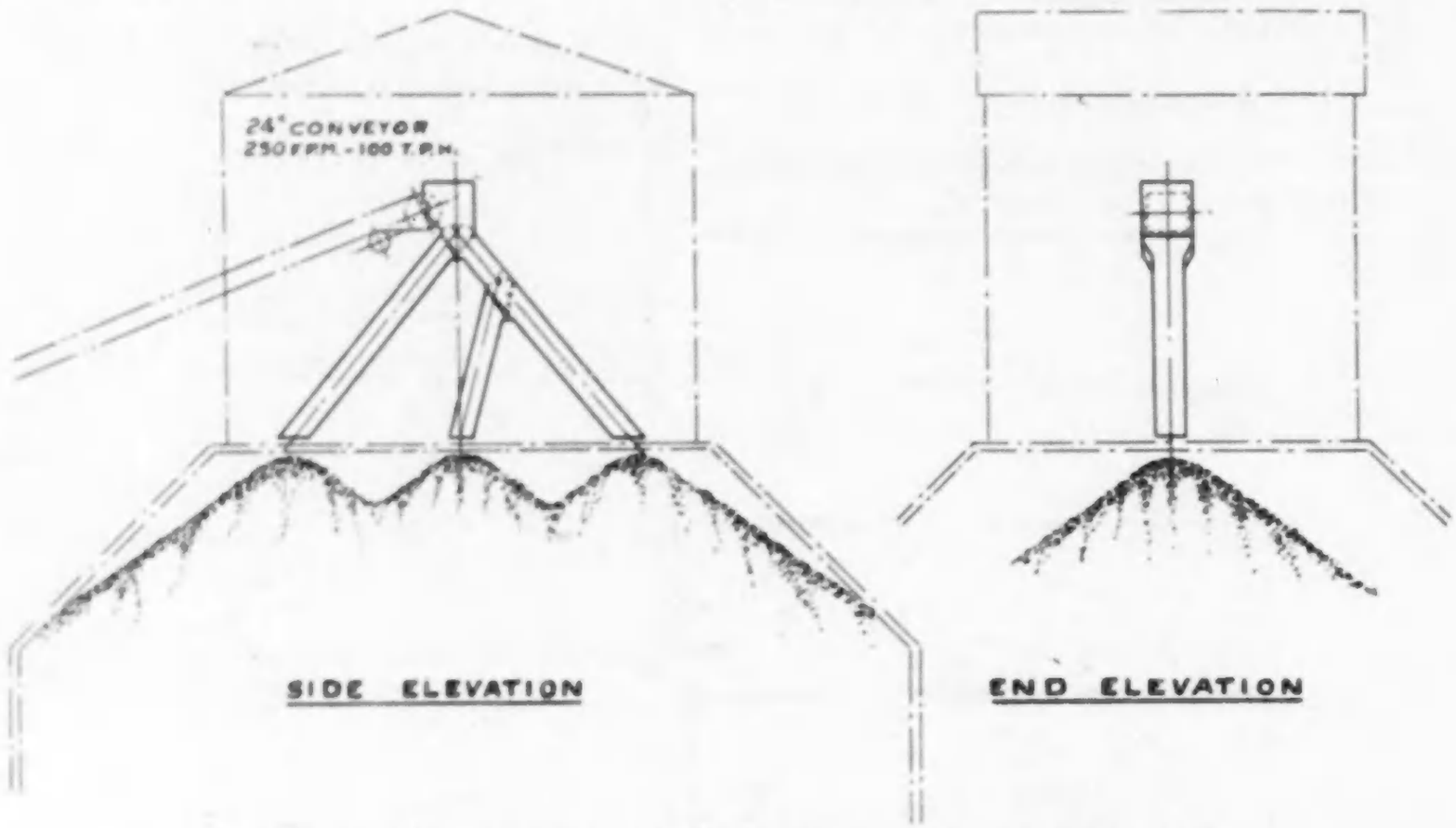

Fig. 5.—Arrangement of distributing chutes over coal breaker.

LIFTING GEAR.

The hoisting gear is electrically driven by means of a motor of approximately 15 h.p. The two winches are geared to one motor by trains of machine-cut gearing, a solenoid brake being provided to prevent a runback in the case of current failure.

ELECTRICAL CONTROL.

The motor is provided with push-button control. To prevent overwinding or failure of the operator to stop the machine when the tipping position is reached, an automatic cut-out is fitted. A similar automatic cut-out is arranged at the bottom of the wind to stop lowering when the tippler is at rest on the foundations. The control gear can be housed in a cabin adjacent to the machine in any convenient position.

SIZING AND CLEANING.

In large installations the practice of installing a Bradford Breaker for sizing and cleaning the coal is increasing. A short description of the Bradford Breaker should therefore prove of interest. An illustration of this machine is given in fig. 4.

The patented Pennsylvania Bradford Coal Breaker, sometimes called the Bradford Cleaner, is a combined coal breaker and cleaner. It breaks, sizes and cleans high ash coals for pulverisers and for all types of stokers and, at the same time, mechanically reclaims the good coal attached to bony.

During the breaking and cleaning operation, it scavenges from the good coal, tramp iron, mine timber, hard bony, sulphur balls and rock, wagon springs, chains, sacking, wire, and other non-essentials. This machine employs a breaking principle in which the coal is mechanically raised and automatically dropped on to heavy perforated steel plates.

Moreover, it acts as a combined coal breaker and mechanical separator of high ash impurities.

Fig. 6.—Pennsylvania hammer crusher.

The coal, which may be Run of Mine or smaller, enters the slowly revolving breaker at one end, where it is caught up by special lifting shelves attached to the screen plates. As each shelf

approaches the top its load of coal is automatically dumped, and is broken down by striking the heavy steel screen plates.

The fine coal thus produced, together with a small proportion of the crushed impurities, escapes through the Bradford screen plates into storage. The lifting operation is repeated until the remaining uncrushed coal is reduced.

As the high-ash refuse in the Run of Mine—bony, sulphur balls and rock—is usually much harder, they resist the tumbling action and are automatically discharged as refuse into a separate chute.

Fig. 7.—Coke wharf and feeders of a coke handling plant.

Fig. 8.—Feeder car of a coke handling plant.

COAL BLENDING AND MIXING.

Owing to the increasing demand for high quality cokes for both blast furnaces and domestic

purposes, the careful selection and blending of coals preparatory to carbonising has for some time demanded particular attention. The typical arrangement of coal-blending plant in use in America consists of a large building divided into four or more bins for the different classes of coal, a Bradford Breaker being placed at the top with an arrangement of distributing chutes or conveyors underneath for delivering the broken coal into any one of the bins. Underneath these bins is a system of short belt conveyors arranged with a regulating device for controlling the thickness of a ribbon of coal. These conveyors converge into a common chute which delivers the coal to the pulverising plant. The regulating gate for controlling the thickness of coal on the belt is capable of regulating the feed within fine limits. In addition to this a system of light fingers resting on the stream of coal is provided and is connected to an electrical cut-out device, which, in the event of any one bin either choking or running short of coal, automatically rings an alarm bell, and stops the mixing conveyors, thus preventing the mixture of coal being spoilt on its way to the ovens.

A second system for mixing the coal consists of a number of rotary tables fitted with adjustable feeds, the coal being ploughed off the rotary tables on to the conveyor leading to the crushers.

A third method, examples of which have already proved very successful in this country, incorporates an altogether different arrangement. In this case, a system of eight track hoppers is provided, fed by four lines of railway. The coal, of different classes, is marshalled at the four sidings and discharged alternatively into one or other of the eight hoppers. These hoppers are divided into groups of four, the coal being taken away by an underground belt. Under each hopper is a simple reciprocating pan feeder. Each group of four feeders is actuated by means of a lay shaft fitted with simple disconnecting clutches allowing any feeder to be stopped or started at will. Each feeder is driven from a crank having an adjustable stroke which enables the feeder to discharge anything from zero to its maximum capacity. Coal from these feeders is then delivered to the Bradford Breaker, or to the cleaning plant or washery if this class of equipment forms part of the installation. In this case it must be noted that while the cost of the building and storage bins has been eliminated, a corresponding amount of sidings and wagon storage must be provided instead.

Fig. 9.—Fraser & Chalmers Robins rotary grizzly.

CRUSHING PLANT.

In order to reduce the coal to the fine size usually required for coking, the installation of an efficient crushing plant is required. It is usual to duplicate the crushers in order to facilitate adjustments and occasional replacements without shutting down the plant. A type of machine commonly used is the Pennsylvania Hammer Crusher, fig. 6, which is of solid steel construction, enabling it to resist the effects of heavy duty and the inevitable strain resulting from rough handling and possible overfeeding.

The machine is provided with a trap or pocket which removes any odd pieces of iron, nuts or bolts small enough to pass through the openings in the Bradford Breaker.

After leaving the crushing plant, the coal is conveyed to the top of the oven bunkers by means of an elevator or inclined belt conveyor. In view of the great height to which the coal has to be elevated, and the large quantities which have to be handled, an inclined belt conveyor is much to be preferred to any system of chain and bucket elevators. The inclined belt conveyor is exceedingly flexible with respect to overload and is practically immune from breakdown of any kind. If bucket elevators are used for a lift of 90 feet or more the unit stresses on the chain, pins and bushes, is exceedingly high, and it is consequently very difficult to avoid heavy wear and tear. The capacity is strictly limited by the capacity of the individual bucket so that anything in the way of overload causes bad spillage, with consequent trouble and jamming in the boot of the elevator. The whole arrangement forms a very vulnerable link in the chain of apparatus between the coal siding and the coal bunker.

At the top of the oven bunkers various means may be adopted to distribute the coal in order to secure the maximum loading into the bunker without hand trimming. A system of chutes, as shown in fig. 5, may be adopted. This, however, entails placing the head end of the conveyor or elevator at a considerable height above the top of the bunker. Alternatively, a short shuttle belt can be employed which will give a very fair distribution of the coal.

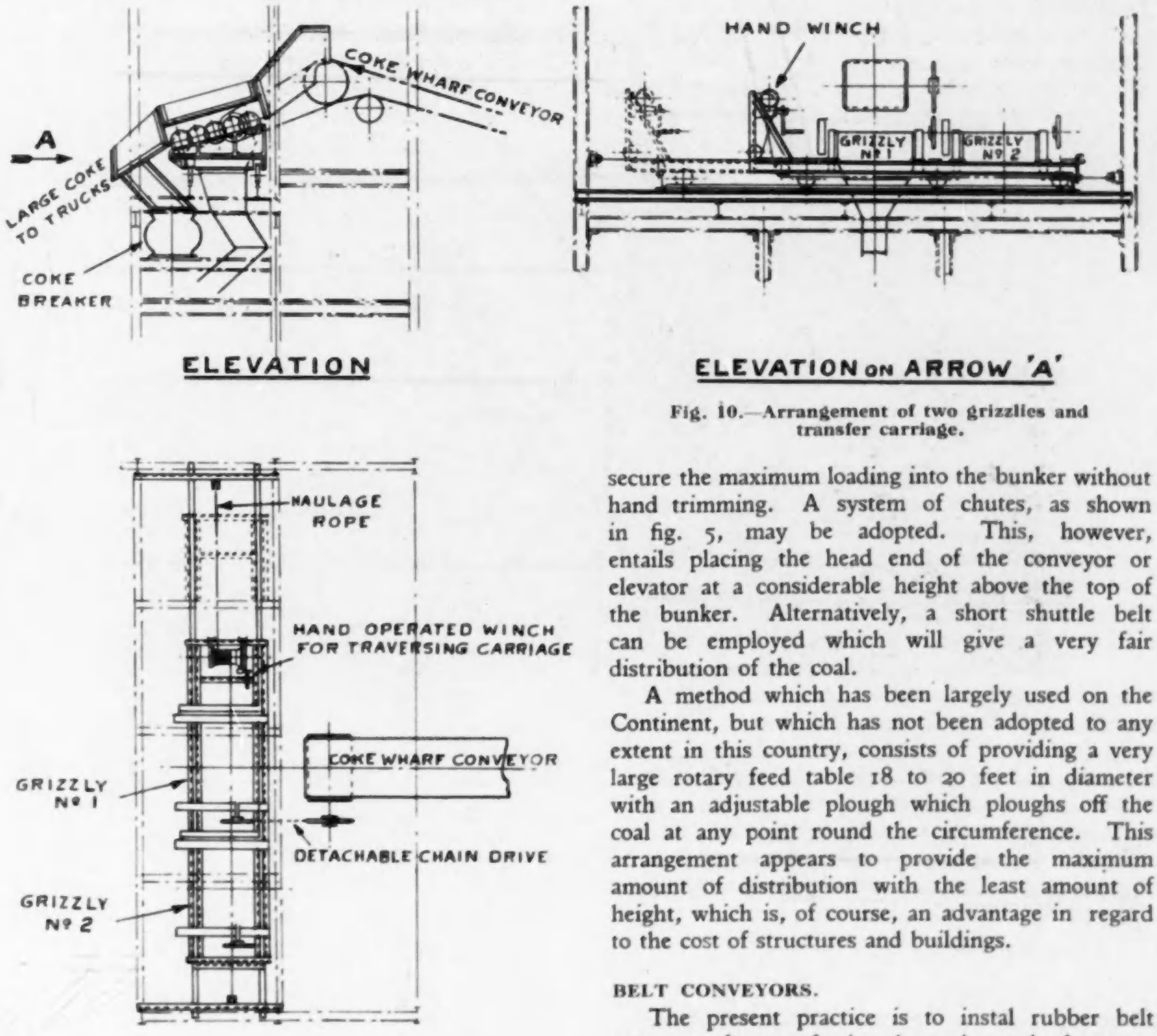

Fig. 10.—Arrangement of two grizzlies and transfer carriage.

A method which has been largely used on the Continent, but which has not been adopted to any extent in this country, consists of providing a very large rotary feed table 18 to 20 feet in diameter with an adjustable plough which ploughs off the coal at any point round the circumference. This arrangement appears to provide the maximum amount of distribution with the least amount of height, which is, of course, an advantage in regard to the cost of structures and buildings.

BELT CONVEYORS.

The present practice is to instal rubber belt conveyors for transferring the coal or coke from one point to another during its passage through the crushing and screening plant and its transit to the bunkers. Much has been written concerning these conveyors, and, simple as they appear to be, the subject of the modern belt conveyor is quite worthy of a comprehensive description to itself. It is sufficient here to point out that simple as a belt conveyor appears, its various components must be accurately designed and accurately and intelligently placed. Moreover, unless the junction

points and transfer points from one conveyor to another (or from the conveyors to the screens or other apparatus in which they have to deliver) are designed and laid out with an intimate knowledge of the behaviour of the material at its various points, smooth and continuous service cannot be obtained.

One of the most difficult features in the design of modern conveyor plant is in connection with delivery chutes, which in practically every case have to be carefully planned to suit the particular conditions under which they will operate. On the coke conveyor system, the old practice of using right-angle or spiral chutes to transfer material from one conveyor running at right angles to another, is usually avoided, such chutes being

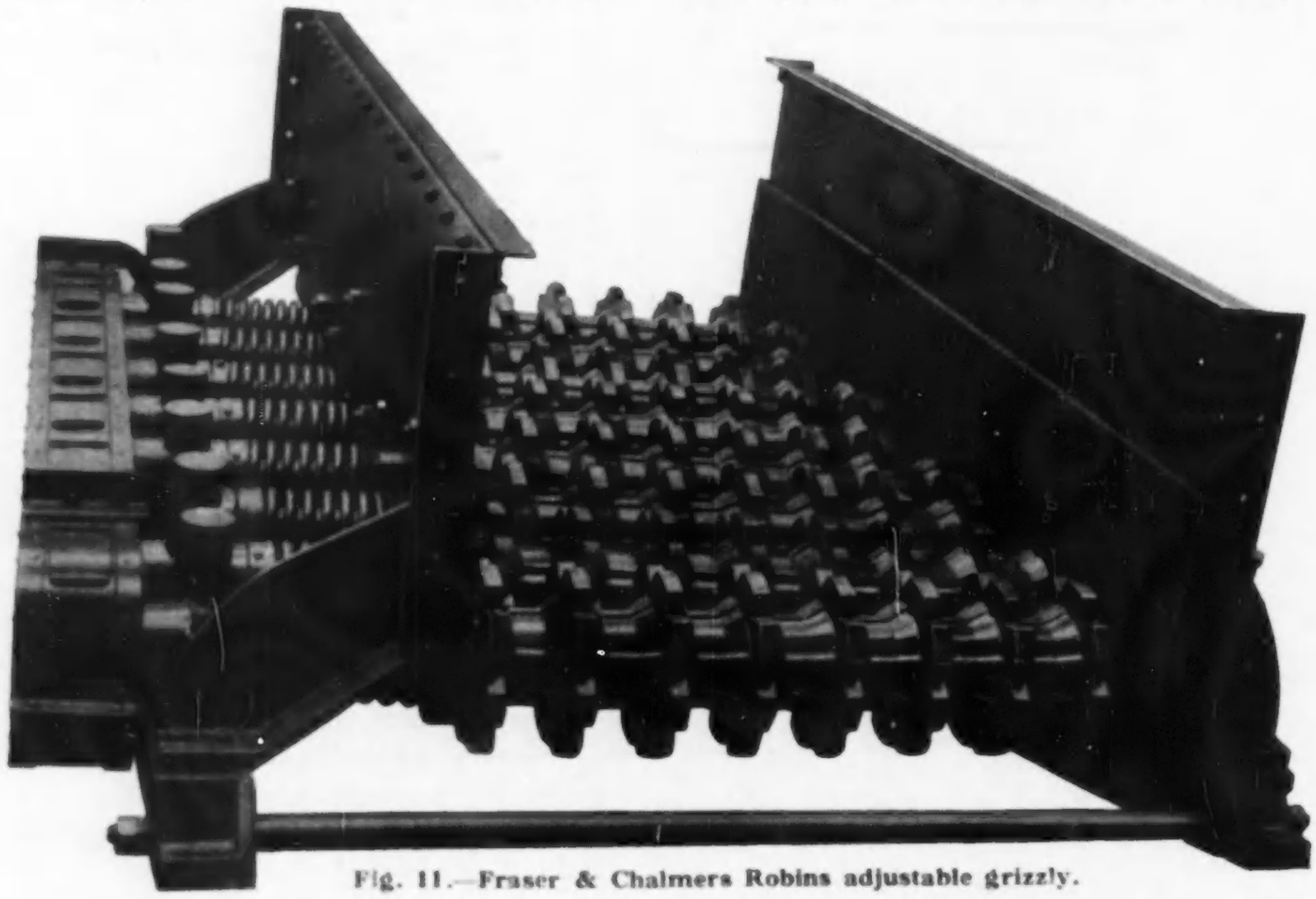

Fig. 11.—Fraser & Chalmers Robins adjustable grizzly.

difficult to maintain in spite of linings of tiles, glass and cast iron plates. In addition, they cause very considerable breakage of the material. By paying a little attention to speeds, these junctions can very often be arranged without any chutes at all. Another point of importance in the design and layout of this type of equipment is that, before designing the buildings and structures carrying the machinery, the conveyors themselves and the whole of the junction points should be definitely planned to provide the minimum in the way of drops or falls from one point to another. Any attempt to rush the design of the buildings and structures and to arrange the machinery afterwards, usually results in cramped junction points and an awkward arrangement of chutes giving spillage and breakage.

So far as the mechanical drives for this class of machinery are concerned, experience has shown that it is well worth while to spend a little money on well-designed, totally enclosed, speed reducing gears in the place of the much cheaper open straight trains of gearing which hitherto have been considered sufficient. These gears will, of course, function, but they are very noisy, and, owing to their exposed positions, are apt to wear rapidly and cause inconvenience and expense.

ELECTRICAL EQUIPMENT.

Electrical equipment for coke oven plant should be of a very robust nature as it usually has to operate in an atmosphere of coal and coke dust. All motors should be continuously rated, including those for truck tipplers. Small auxiliary motors for capstans, boom hoists and small haulage winches for moving wagons, can be one hour rated. The larger motors should be as open and accessible as is practicable and suitably housed in convenient parts of the buildings. The larger motors should be fitted with iron-clad oil immersed starting apparatus, the smaller machines being preferably of the squirrel cage type connected straight on to the mains through an iron-clad three-pole oil immersed switch.

Further, the extra cost entailed in providing sequence starting and remote control is generally well worth while in a large plant, as it considerably facilitates smooth and continuous operation and reduces the amount of operating labour to a minimum. These points refer particularly to alternating current machinery, as in the large modern plants the use of D.C. machines is now quite exceptional.

LADDERS AND PLATFORMS.

The number of ladders and platforms required is so small compared with the plant as a whole, and the ultimate convenience to those in attendance on the plant can be so greatly affected by the manner in which they are laid out and provided, that a little trouble in arranging them will prove of ultimate advantage. Wood flooring and galleries are both cheaper and much more convenient in actual use than steel plate or open steel floorings. Wood floorings are especially suitable for inclined galleries, as they afford very much better foothold and do not become slippery with grease and moisture. In the machinery houses, the floorings can be of concrete if desired.

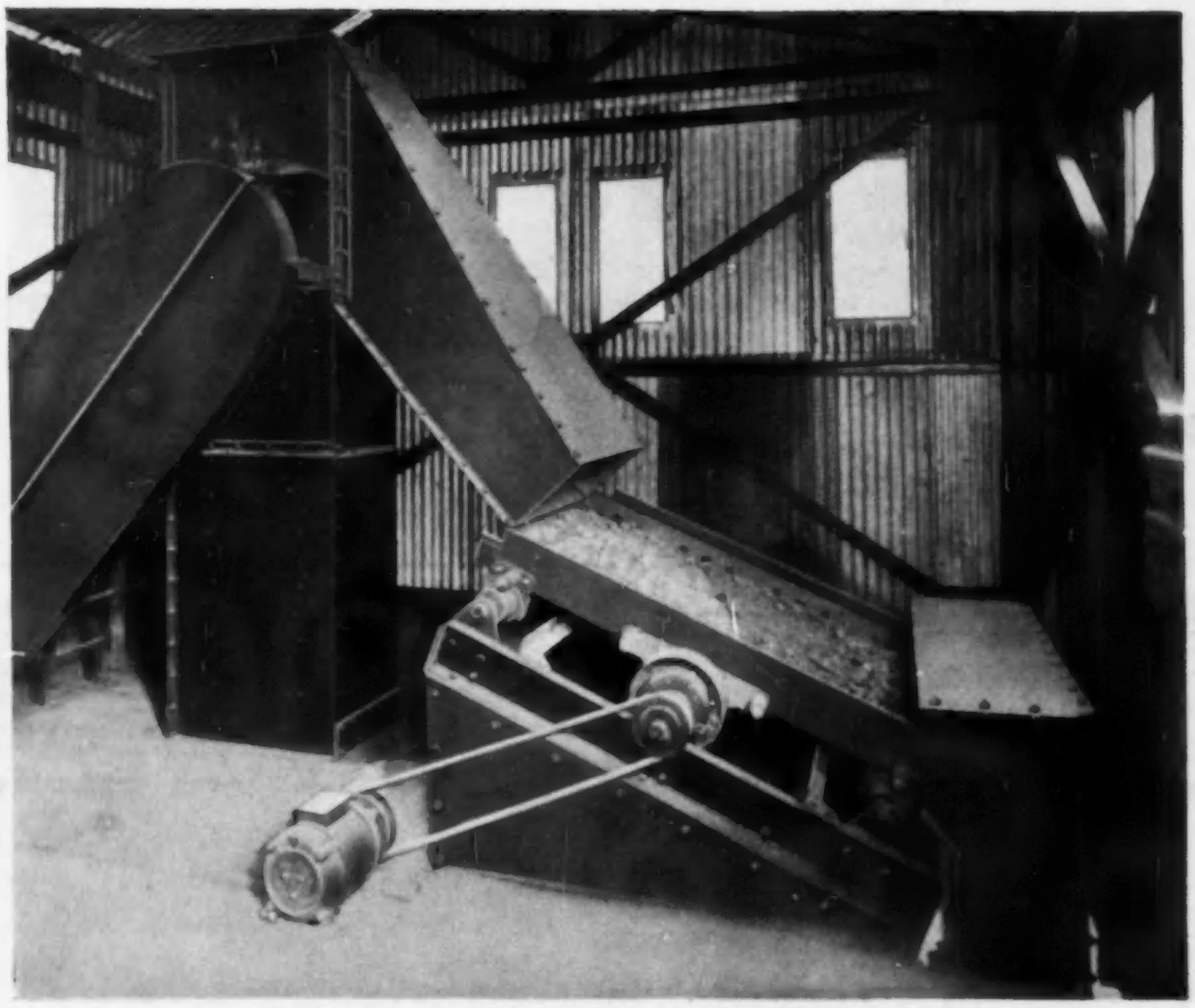

Fig. 12.—Fraser & Chalmers Robins Gyrex screen.

COKE HANDLING AND SCREENING PLANT.

The usual practice is for the coke, after being quenched, to be discharged from the quenching gear on to an inclined wharf built of ferro-concrete and covered with cast iron plates. Running parallel with this wharf is a trench, at the bottom of which is located a rubber belt conveyor inclined upwards to deliver the coke to the primary screening plant. The system which has for many years been common practice in America, is to provide an arrangement of roll feeders in 6 feet lengths throughout the whole length of the wharf, preceded by balanced sectional feeder gates which can be opened one at a time, the coke sliding down the inclined coke wharf and being fed evenly and continuously by the roll feeders on to the belt. This arrangement, which is illustrated in fig. 7, gives excellent results and, provided that the gates are only open one or two at a time, prevents crowding the coke on to the belt. Spillage in the conveyor pit is also avoided, while good screening is obtained owing to the continuous and even feed into the screening plant.

The roll feeders are sometimes eliminated on the ground of expense, in which case the regulation of the feed on to the belts is entirely in the hands of the operator. Where these roll feeders are omitted, it is usually found that the operator for the first few months invariably slams two or three of the gates wide open, allowing the coal to rush down on to the belt. This is bound to result in considerable spillage. The load of coke travelling up the incline may be as much as 100 per cent. above normal, which over-strains the belt and causes trouble with the joints besides impairing its life. The screens become overcharged, thus reducing their efficiency. With a little care and proper supervision, however, coke can be suitably regulated without the use of roll feeders. Another very convenient method which incurs less expense than the standard roll feeder arrangement, is to mount two sections of roll feeders on an electrically operated travelling carriage which moves up and down in front of the bench, registering with two pairs of gates at a time, as shown in fig. 8.

The main coke belt from the wharf is usually

from 30 in. to 36 in. wide and should not run at a greater speed than 250 ft. per minute. The radius of the curve from the horizontal to the inclined portion of the belt should not be less than 200 to 250 ft. This will depend to some extent on the length of the horizontal portion of the belt. If this radius is made too small, the belt will take its natural catenary and lift right off the idlers, causing heavy spillage. The angle of incline to the belt should not exceed 18° for a run of oven coke. With a smaller size this figure may, if necessary, be exceeded.

PRIMARY SCREENING PLANT.

Primary screening plant usually consists of one or more rotary grizzlies, fig. 9, placed at the head end of the main coke conveyor. A convenient arrangement is to mount two of these grizzlies on a transfer carriage, fig. 10, so that either of them can be brought into operation in a few minutes, thus enabling the size of coke to be varied according to the market. A recent improvement consists of an adjustable rotary grizzly, fig. 11, which, by a simple arrangement of adjustable discs, makes it possible to vary the product within certain limits. After leaving the rotary grizzly a suitable arrangement of chutes is provided, whereby the large coke can be passed on direct to the loading conveyor mounted on an adjustable boom, which can be raised or lowered to give minimum drop into the railway trucks. Alternatively, the coke can be by-passed through a coke cutter where the cut product joins the undersize from the rotary grizzly and passes on to the secondary screening plant. If necessary, the coke can be taken out as a separate product. The primary screening plant is connected to the secondary screening plant by a suitable arrangement of belt conveyor and gallery.

SECONDARY SCREENING PLANT.

The layout of the secondary screening plant will, of course, largely depend on the number and size of the products, but assuming some such sizes as 2½ in., 1½ in., ¾ in. and ⅜ in., the following arrangement is typical of modern practice.

The first screen consists of a medium speed vibrating screen of the Gyrex type, fig. 12, in which the screening medium is rapidly agitated by a short throw eccentric, one end being supported on cantilevered springs.

The undersize from this screen would then be passed on to two or more screens of the Vibrex type, fig. 13, which in construction consist of a rigid steel frame mounted on springs agitated by a high speed shaft carrying unbalanced discs, capable of adjustment so as to vary the amount of vibration from zero to a maximum. A feature of this screen is that the whole of the screening surface is uniformly agitated; the capacity is high and the efficiency quite exceptional.

Fig. 13.—Fraser & Chalmers Robins Vibrex screen.

Diesel-electric Locomotives for the Indian State Railways.

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Traction Dept. of The General Electric Co., Ltd.

THE improvement effected in the design of Diesel engines during recent years and their reliability as demonstrated under conditions of heavy duty, have turned the attention of locomotive engineers the world over to the possibilities of the employment of such units as a source of power in place of steam on locomotives.

The simplicity which accompanies the use of solid injection and the higher speeds which modern design finds it practicable to employ, render it possible to accommodate engines of adequate power within the limits of space and weight permissible on locomotives.

The incentive to seek an alternative to the steam locomotive is considerable, especially in localities where water is scarce or bad and coal expensive or of poor quality. Even where these conditions do not obtain to any extent the normal maintenance and stand-by charges of steam locomotives are sufficiently heavy to induce those responsible for their operation to investigate an alternative which shows itself likely to reduce these costs.

COMPARISON OF DIESEL & STEAM LOCOMOTIVES.

The Diesel locomotive has a primary advantage in the high thermal efficiency of its prime mover. It has been found that its fuel consumption under average conditions is about one-sixth that of a coal fired steam locomotive, so that with fuel oil at three times the price of locomotive coal, the fuel cost is halved. Furthermore, the Diesel locomotive incurs no stand-by charges, as the engine may be shut down whenever the locomotive is out of operation, even though this be only for a five minutes halt at a station.

There is no boiler or fire box demanding regular attention and periodical repair. Moreover, fuel oil is more easily transported than coal, while a great advantage is that the Diesel locomotive can be prepared for service in a minute or two, whereas

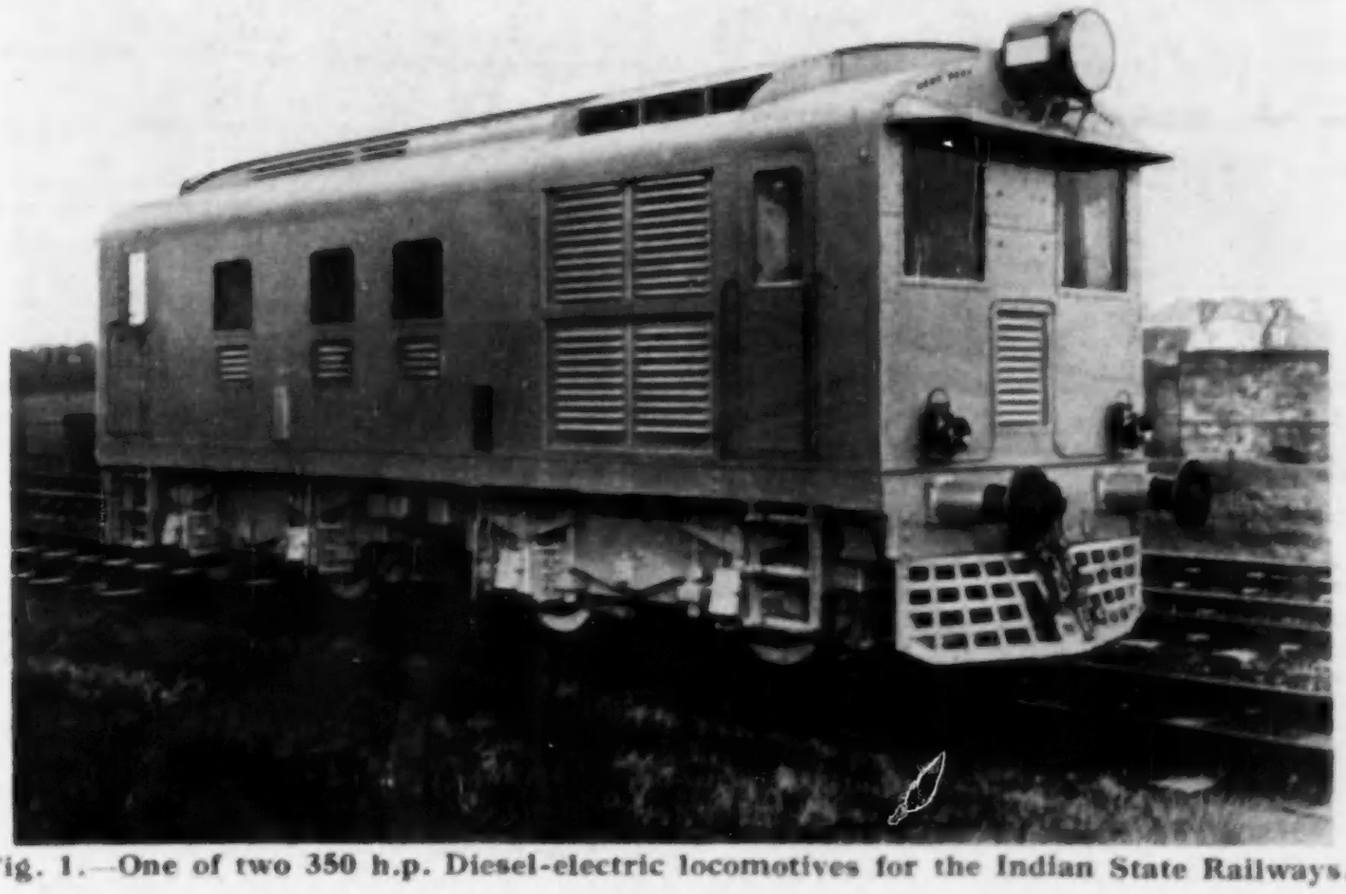


Fig. 1.—One of two 350 h.p. Diesel-electric locomotives for the Indian State Railways.

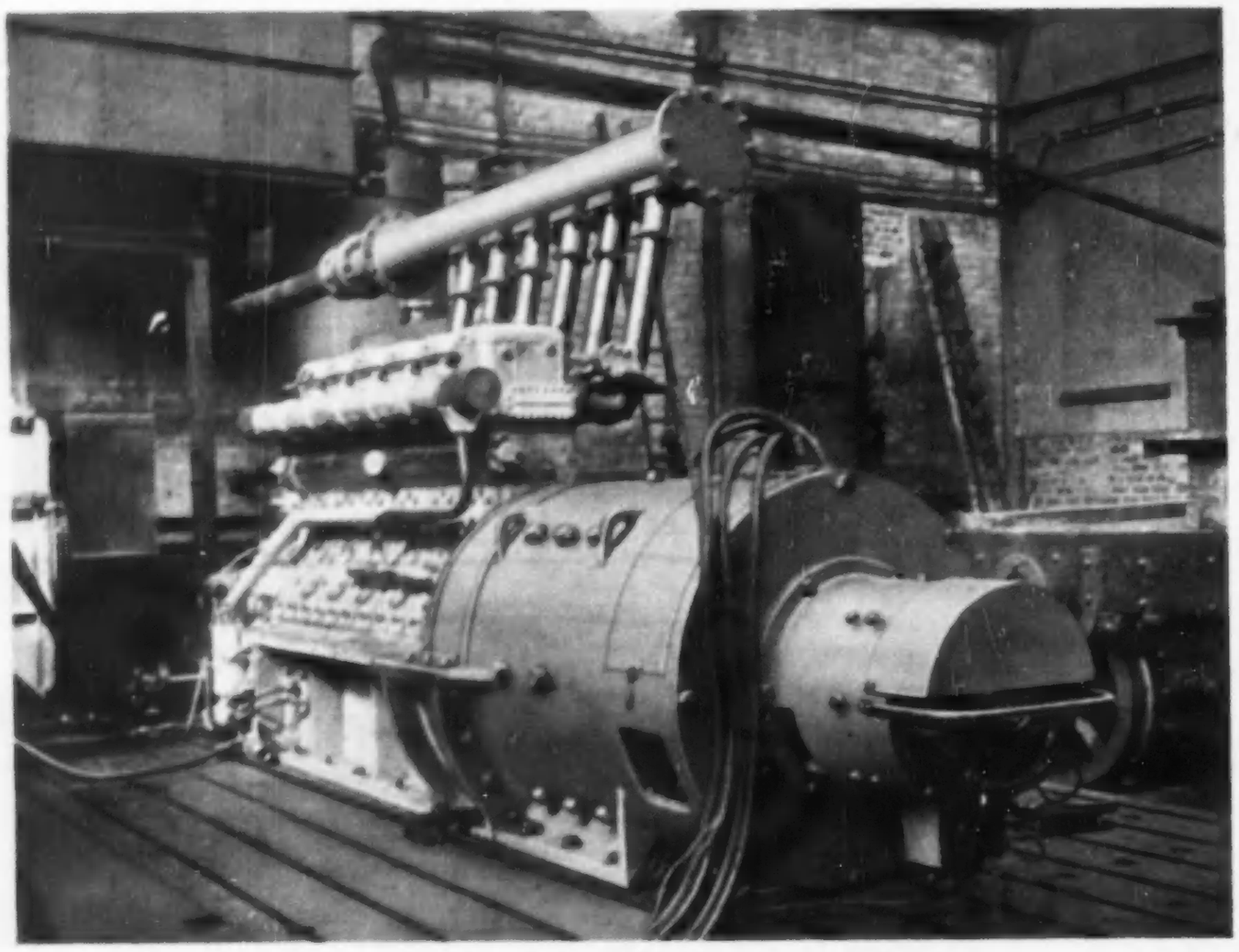


Fig. 2.—Power unit erected on test bed.

some considerable time must elapse before a steam locomotive is ready for duty.

The amount of make-up water required by the Diesel locomotive is small, being only that necessitated by evaporation in the cooling water circuit. As a consequence, the Diesel locomotive is eminently suitable for traversing long arid stretches of country where, with steam locomotives, water towers and filling troughs must be maintained, every drop of water for which must be hauled long distances at great expense.

With the steam locomotive again, it is essential to employ two men on the footplate, as the firemans' task is continuous.

In the case of a Diesel locomotive fitted with a dead man's handle, however, there is no necessity for a second man and the saving thus effected may well be found on branch lines with sparse traffic to turn the service from a non-paying to a revenue earning proposition.

The problem of transmitting the drive from the engine crankshaft to the driving wheels is of major importance in Diesel locomotive design, the torque-speed characteristics of the engine being fundamentally dissimilar from those of the steam engine. The mind of the locomotive engineer naturally turns first to a mechanical drive incorporating clutch and gear box on the lines of automobile practice. It is now accepted, however, that above small powers, the mechanical drive is unsuitable.

Hydraulic transmission has been tried but is heavy and cumbrous, while transmission by compressed air, which is being tried on the Continent, seems likely, by reason of its inefficiency, to militate against one of the primary advantages of the Diesel drive. There remains, as the outstanding practicable proposition for heavy duty locomotives, the electric drive, and it is this method of transmission which has been adopted in the majority of modern installations.

The General Electric Co., Ltd., has recently completed preliminary trials of two Diesel-electric locomotives on a branch line of the L.M.S. Railway in Scotland. These locomotives, the electrical equipments of which are constructed in accordance with the Oerlikon system, are required for duty on short runs on both main and branch lines of the North Western Railway of India, and are intended to meet the steadily increasing competition from road transport experienced during the last two or three years.

For this purpose relatively high speed is of paramount importance while, with native drivers,

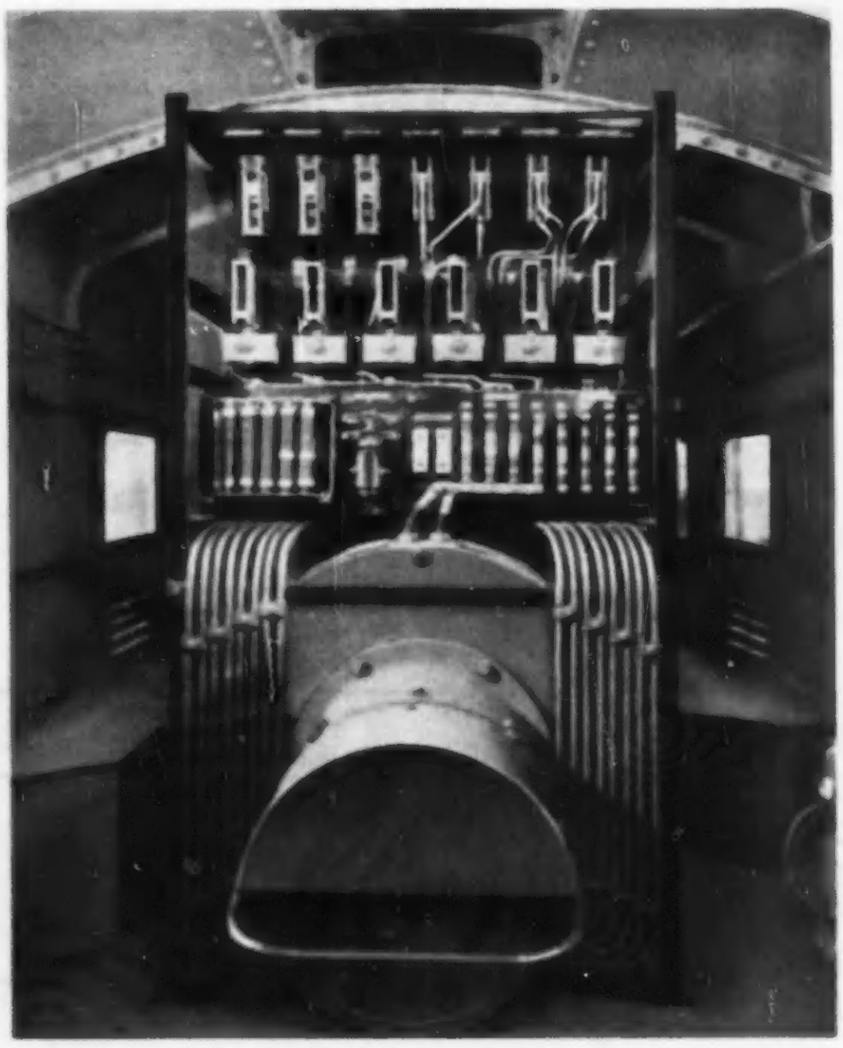


Fig. 3.—View inside centre compartment, showing main control panel mounted over generator.

ease of control and maintenance are further essentials. It was specified that with a light load on a level track a speed of 50 to 55 miles per hour should be possible, while with a train consisting of three bogie vehicles, having a gross weight of 100 tons, the normal running speed should be 47 m.p.h., diminishing to 36 m.p.h. on a 1 in 300 gradient and to 13 m.p.h. on a 1 in 50 gradient.

This means that the power of the locomotive would be intermediate between the 4-4-0 type steam passenger locomotive, which has a tractive effort of 19,000 lbs. at starting, and the ordinary rail motor coach with trailer.

MECHANICAL CONSTRUCTION.

The locomotives are of the double bogie type without articulation, the wheels being side equalised in order to give easy riding qualities over rough tracks.

The superstructure follows the recognised design for electric locomotives and consists of a long cab divided into three compartments. Driving compartments are arranged at both ends, each containing a master controller, driver's brake valve for the vacuum brake, engine indicators, lighting switches, brake pressure gauge and other controls arranged for the driver's convenience, while the central compartment houses the Diesel engine, generator, oil and water cooling radiators, and other equipment. One of the driving positions is

Fig. 4.—Driver's controls and indicating instruments in one of the driving compartments.

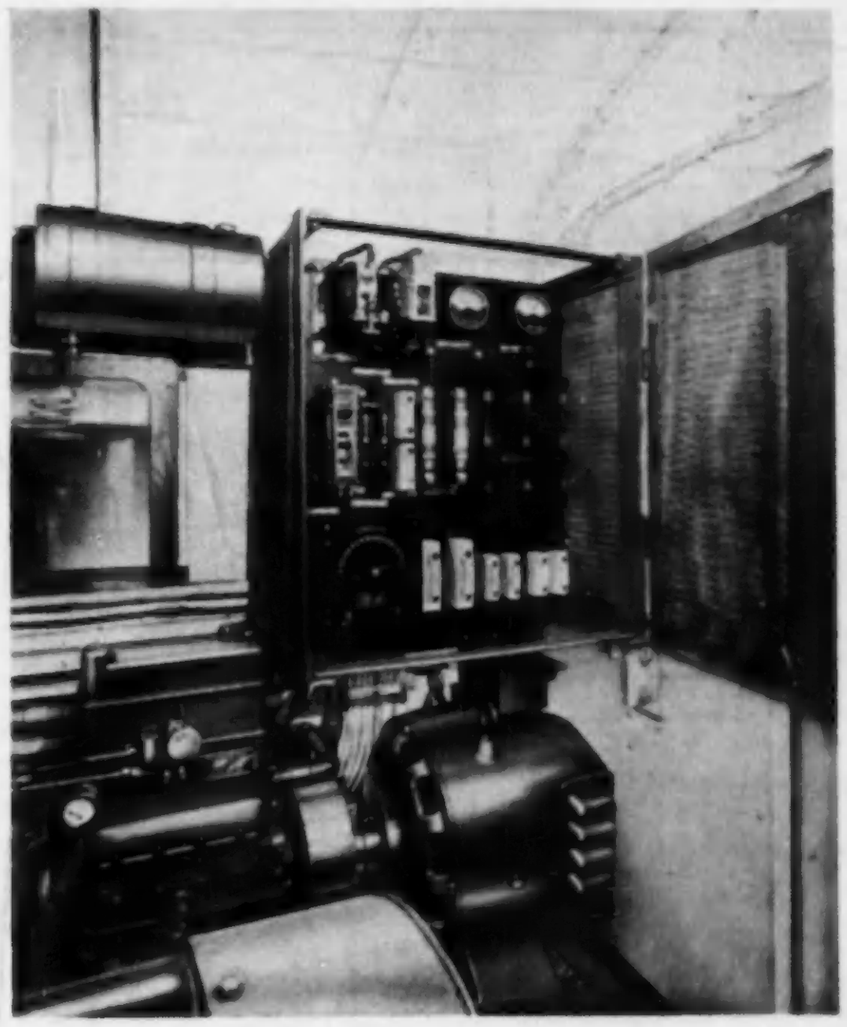


Fig. 5.—5 kW petrol engine driven auxiliary generator and control panel.

illustrated in fig. 4 from which it will be seen that control of the locomotive has been reduced to its simplest form.

PRINCIPAL DATA.

The principal dimensions and data relating to the locomotives are as follow :—

Length over buffers	35ft. 10ins.
Height over cab	12ft. 9ins.
Width overall	9ft. 0ins.
Total wheel base	23ft. 0ins.
Wheelbase of each bogie	7ft. 8ins.
Centres of bogies	16ft. 0ins.
Distance from rail to platform ..	4ft. 1in.
Diameter of wheels	3ft. 0ins.
Track gauge	5ft. 6ins.
Weight in running order	48 tons
Maximum Tractive effort	10,000 lbs.
Continuous h.p. of Diesel engine ..	350 h.p.
Number of driving motors	4

In passing, it may be mentioned that in order to carry out trials in this country the design was so arranged that with few modifications the locomotives could run on British tracks having a gauge of 4ft. 8½ins., and would conform with the British loading gauge. Wherever possible, components such as tyres, spring brake blocks, sand boxes, etc., are constructed to the standard types and sizes used on the Indian State Railways, thus making these

components interchangeable with those on existing stock.

DIESEL ENGINE.

The Diesel engine is of the high speed type built by Messrs. William Beardmore & Co., Ltd., and functions on the four cycle fluid pressure injection system. These engines have been operating for some years on the Canadian National Railways, the design being originally developed to provide a

Fig. 6.—Armatures of main generator and exciter mounted on common shaft.

compact lightweight engine of steel construction having a low weight power ratio, which in this particular instance has the extremely low value of 21lbs. per b.h.p.

The six cylinders of the engine are positioned in line, and have each a bore of 8¼ inches and a stroke of 12 inches, the engine developing 350 h.p. when running at 900 r.p.m. For short periods this can be increased to 420 h.p. The engine forms a self contained unit complete with its own water and lubricating oil pumps, both of which are automatically controlled. Fig. 2 shows the engine and generator erected on the test bed.

An important constructional feature is the steel monobloc crankcase which forms a rigid unit structure sustaining the longitudinal and transverse stresses set up by the motion of the moving parts. The crankcase is bored out to receive the steel liners forming the cylinder walls, annular spaces being left between the liners and crankcase to form a water jacket. Large inspection doors are provided to give access to the big end bearings while strong base supports, cast integral with the crankcase, enable the engine to be rigidly bolted to the underbed.

The lower part of the crankcase consists of an alloy steel casting and forms the oil sump, the underside of which is arranged for bolting to the longitudinal members of the locomotive, the end being extended for carrying the generator.

Both the forged steel crankshaft and the connecting rods are balanced and tested for weight distribution, the big end bearings being fitted with adjustable liners to take up wear. Aluminium alloy pistons, machined all over and fitted with four cast iron piston rings, are employed, while the cylinder head is also made of aluminium alloy and is provided with large water cooling spaces.

Each cylinder head carries two exhaust and two inlet valves in addition to a central automatic spray

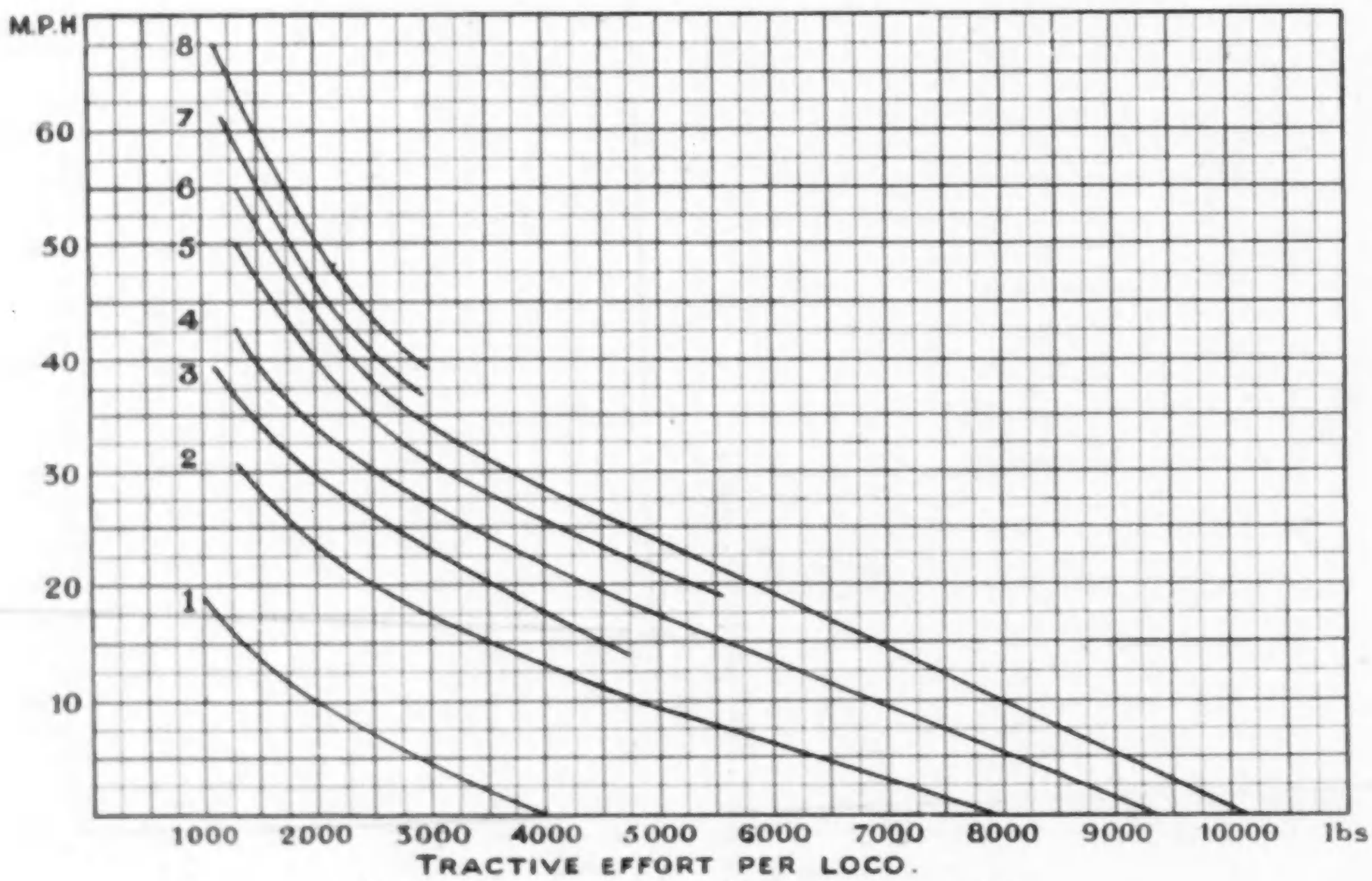


Fig. 7.—Performance curves of Diesel-electric locomotive.

atomiser. Compression release is obtained by lifting the inlet valves, both these and the exhaust valves being actuated by tappets from the camshaft. Motion from the tappets is transmitted to the train of gears housed in a special end casing which also contains the gear wheel spindles for driving the cooling water and oil circulating pumps.

The fuel pump possesses three separate plungers,

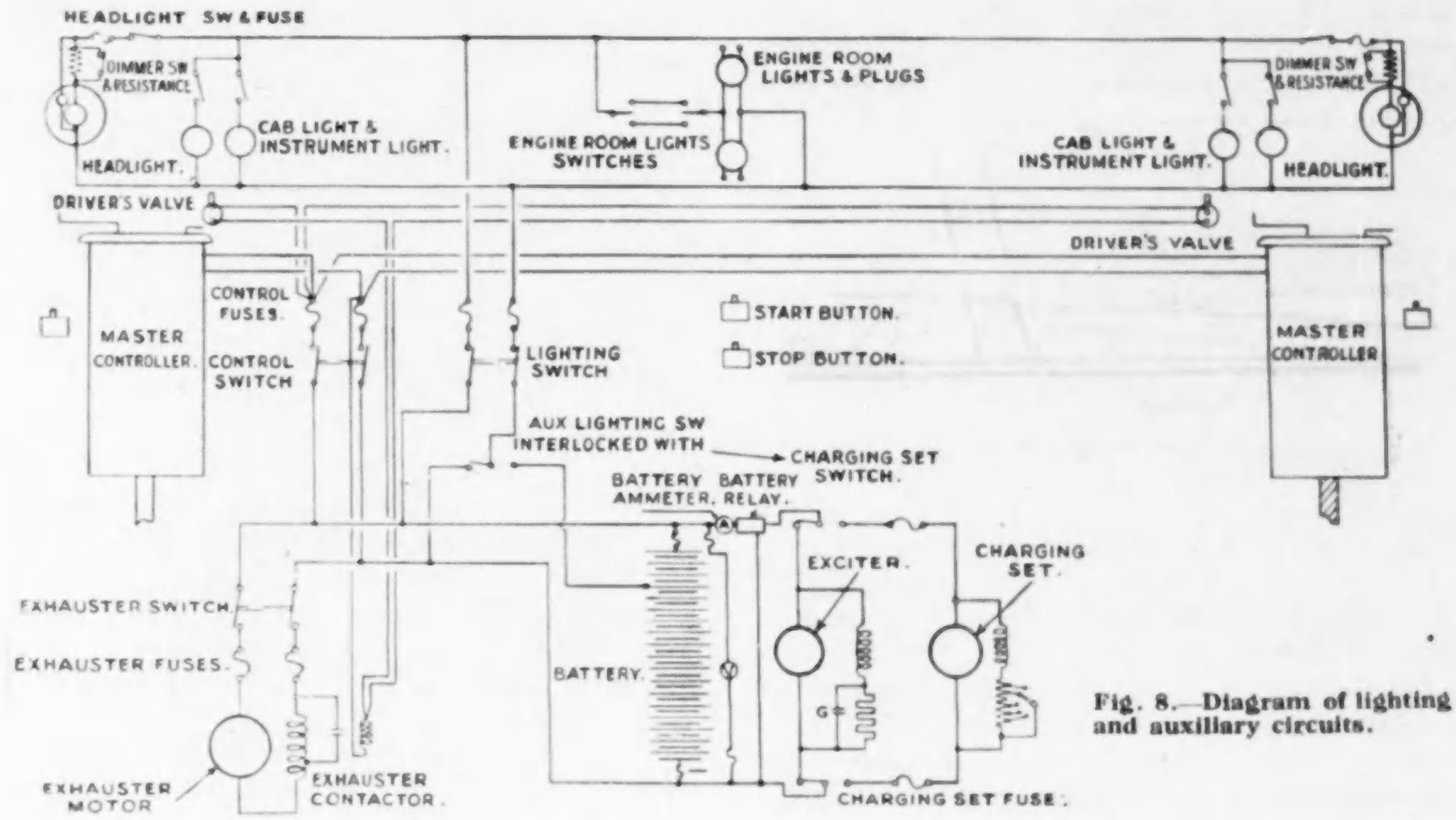


Fig. 8.—Diagram of lighting and auxiliary circuits.

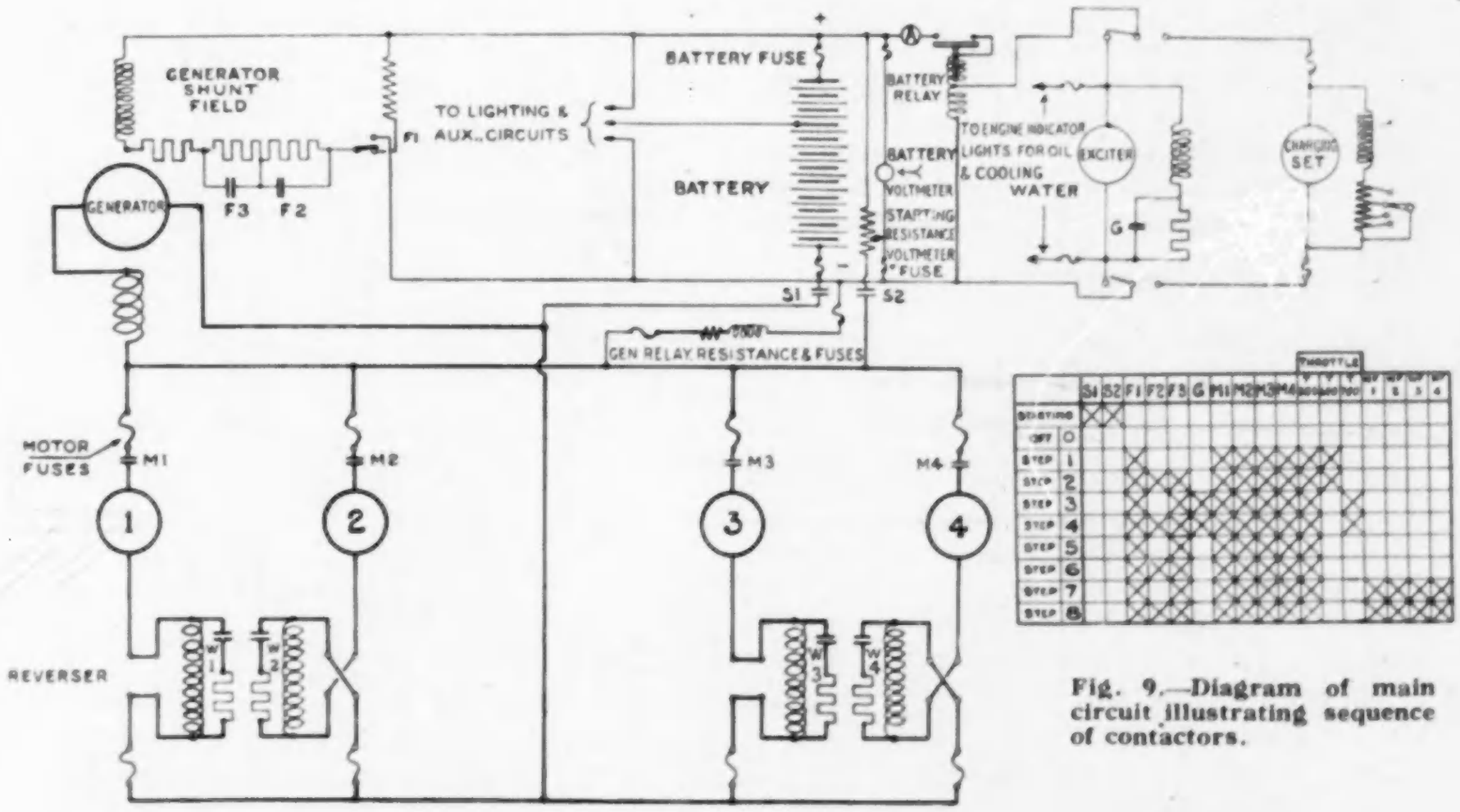


Fig. 9.—Diagram of main circuit illustrating sequence of contactors.

valves by means of pushrods and valve levers mounted in the cylinder head, the valve gear being entirely enclosed by a light aluminium cover. The camshaft is driven from the crankshaft through a

each serving two cylinders, and a primary pump maintains a low pressure on the suction side of the fuel pump and atomiser in order to give correct timing. The injection is timed and the

engine output controlled by varying the effective pump delivery stroke, any excess oil being returned to the fuel tank by a by-pass gear.

ENGINE SPEED CONTROL.

Control of the locomotive speed of the engine is effected primarily by variation of the speed of the governor, the latter being arranged with four

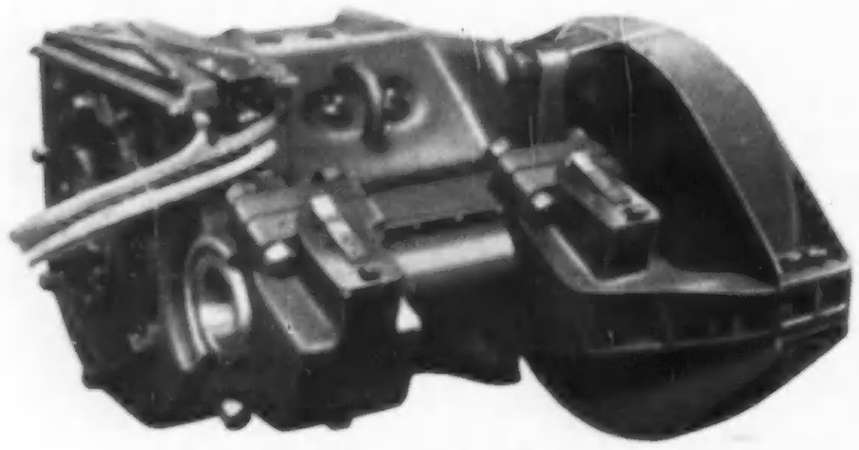


Fig. 10.—One of the four axle-hung motors.

definite settings giving speeds of 350, 600, 750 and 900 r.p.m., while an automatic overspeed device is fitted which prevents the engine exceeding a speed of 1,050 r.p.m. by venting the fuel pump.

The governor setting for these four speeds is controlled by a series of electrically operated valves operated from the master controller in the driver's compartment.

It will be appreciated that this method of controlling speed by altering the governor setting affords several distinct advantages, among which may be mentioned the considerable economy gained in fuel consumption when travelling down long gradients, and the simple manner in which a variable h.p. output from the locomotive is obtained.

ENGINE LUBRICATION.

Lubrication is carried out by a pressure system in which oil is drawn from a storage tank by a pressure pump at the gearcase end of the engine. It is then forced through filters on the engine, through the crankshaft to the journals and pins and to the big end bearings. Another distributor carries oil to the centre of the camshaft, from which the camshaft bearings are lubricated. The oil is then returned to the sump, whence it is extracted by a scavenge pump which returns it through a cooler and filters to the storage tank.

Monitor valves are inserted in the water and lubricating oil circulating systems and are fitted with electrical contacts which, in the event of a failure of one or both systems, cause pilot lamps on the instrument panel in each of the driving compartments to be extinguished, thus giving visible warning.

COOLING SYSTEMS.

Two radiators of the spiral gilled tube type are mounted one on each side of the locomotive for cooling the lubricating oil and the cooling water respectively. Large fans, driven from the engine, draw air through each of the radiators, discharging it *via* ducts leading to the roof of the locomotive. A thermostat-controlled by-pass ensures that the cooling water reaches the correct temperature as quickly as possible after starting by allowing the water to short circuit the radiator. Temperature indicators for both lubricating oil and cooling water are mounted on the instrument panels in the driving compartments.

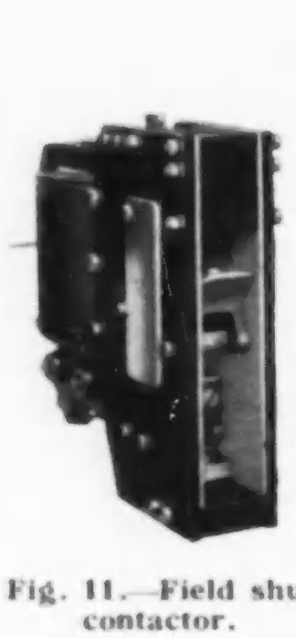


Fig. 11.—Field shunt contactor.

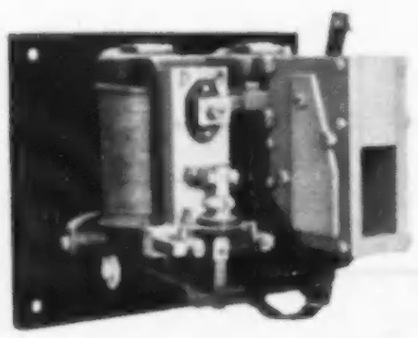


Fig. 12.—(Above) Battery cut-in and cut-out relay.

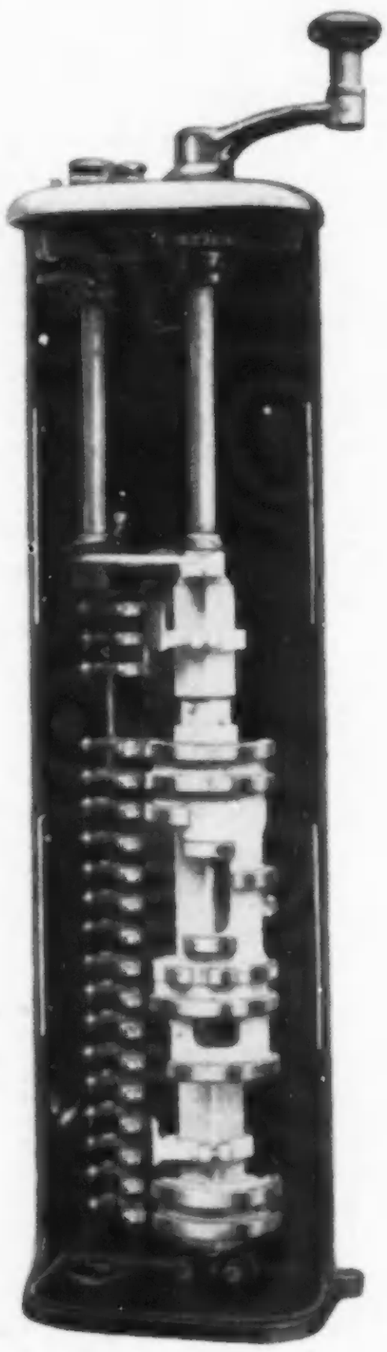


Fig. 13.—(Right) Interior of master controller.

The necessity for these refinements will be appreciated when it is realised that in the cold weather on this section of the Indian Railways the temperature frequently drops below freezing point, while in the hot weather the air temperature rises to 120° F.

A tubular type exhaust muffler is mounted on the roof of the cab, each cylinder being connected separately by a pipe fitted with a flexible coupling.

FUEL STORAGE.

Sufficient fuel oil is carried in a tank of 150 gallons capacity for the locomotive to run for seven hours on full load. The oil is delivered to the main fuel pump at a pressure of 40 lbs. per sq. inch by a booster pump mounted on the engine.

STARTING ARRANGEMENTS.

The engine is started by supplying current from a storage battery to motor the generator. The control is so arranged that it is impossible for the driver to start the engine on full compression. This is an important point, as it considerably reduces the strain of starting on the battery. Furthermore, a safety device is introduced in the form of a special relay which prevents the generator passing a heavy charging current to the battery should the driver keep the starting connections in operation after the engine has started. The control consists of a push button suitably interlocked with the de-compression lever, both of which are mounted on the engine.

Three push buttons for stopping the engine are also provided and these are situated one in each driving position and one in the engine compartment. Thus the driver has always close at hand the means for stopping the engine either under normal conditions or in an emergency.

ELECTRICAL EQUIPMENT.

The electrical equipment includes a main generator, an exciter, four traction motors, electrical auxiliaries, control equipment and other apparatus.

The main generator is nominally rated at 250 kW and supplies current at pressures varying between 100 and 800 volts, depending on the speed and load. Only one bearing is included in the construction of the machine, this being situated at the exciter end of the armature shaft, the other end of which is coupled to the engine flywheel by means of a solid spigot and bolt coupling. This construction reduces the stresses which normally would be set up by the use of two bearings in the generator in addition to those of the engine. The single bearing employed is of the Hoffman roller type carried in a spherical seating which further ensures self-aligning of the shaft.

The frame of the generator is of cast steel and is flanged at the coupling end for bolting to a similar flange provided on the engine bedplate. As the unit is carried as a whole on the main frame of the locomotive any tendency to distort is eliminated.

In order to obtain a heavy drooping characteristic the generator is provided with an inverse compound winding which has the effect of limiting the output of the machine, the windings being so proportioned that the engine can never be seriously overloaded. A simple form of adjustment is provided in the form of resistances which will allow any subsequent alteration to be made to suit any special service conditions.

EXCITER.

The overhung exciter follows normal practice and is rated at 10 kW with a normal voltage of 120. Actually the exciter would be more correctly termed

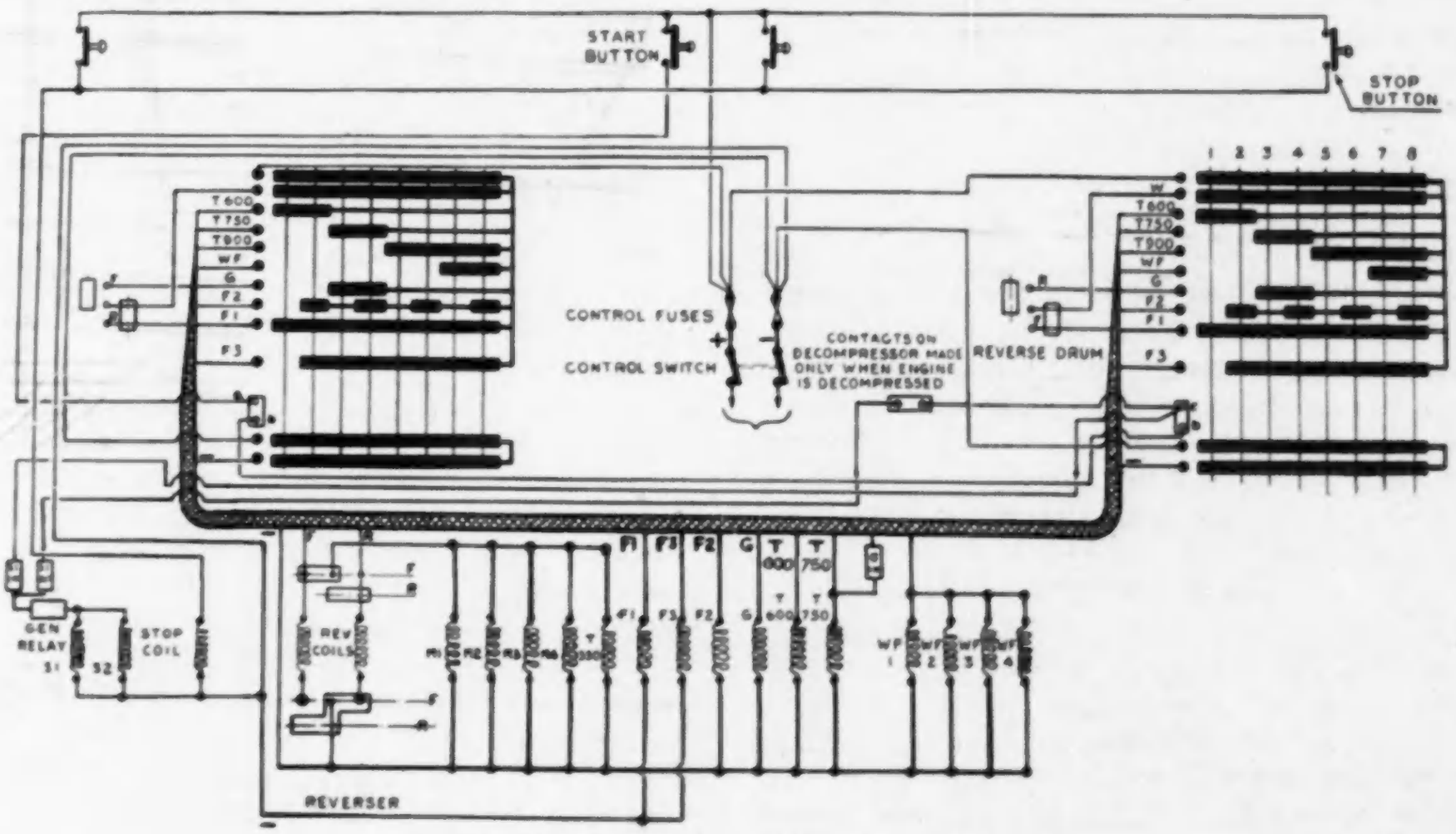


Fig. 14.—Diagram of connections of control circuits.

an auxiliary low tension generator as it supplies current when running at speeds of 750 and 900 r.p.m., not only to the main generator field but also to the vacuum brake exhauster motor, while it also assists in maintaining the battery in a charged condition. An automatically operated series resistance inserted in the shunt field enables the exciter to maintain the same voltage at both the speeds indicated.

Below these speeds, that is at 400 and 600 r.p.m., the battery supplies the total low tension current

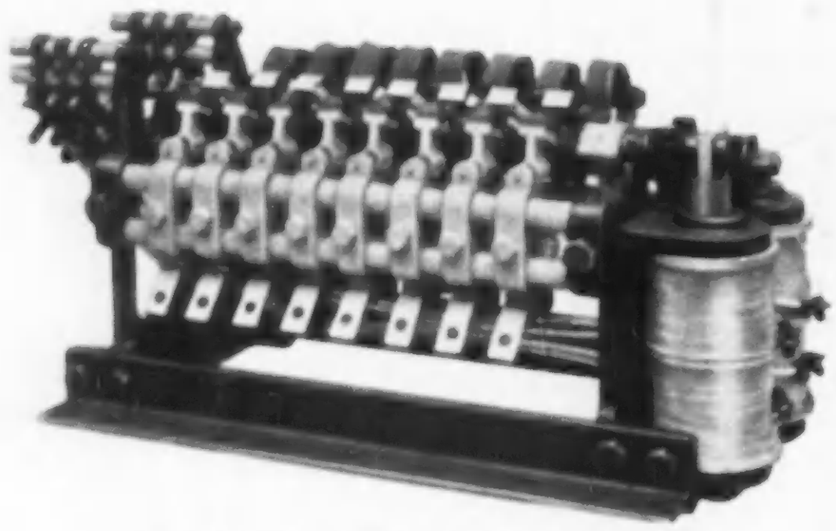


Fig. 15.—Solenoid-operated reverser.

required by the generator field, exhauster motor, lighting and the control system.

As in the case of the main generator, the exciter is designed with a slightly drooping characteristic so that it automatically protects itself from heavy overloads. The nominal voltage of the low tension circuit is 110.

MOTORS.

The traction motors (fig. 10) of which there are four, follow standard practice and are designed to meet the maximum service condition without undue heating. Their normal one hour rating is 120 amperes at 600 volts, but they will carry considerably greater loads than this, while in order to give the normal running speed of 47 miles per hour the motors are arranged for field shunting, approximately 35 per cent. field shunt being provided. The motors are axle hung, their drive being transmitted to the axles by single reduction spur gearing enclosed in oil tight gear cases. The armatures are carried in grease lubricated roller bearings.

A series of curves is given in fig. 7 illustrating the performance characteristics of the locomotives.

AUXILIARY EQUIPMENT.

Apart from the exciter which has already been described, a small petrol engine driven generator, fig. 5, is provided for the purpose of maintaining the battery in a properly charged condition. This auxiliary is rated at 5 kW and supplies direct current at 110/135 volts at a speed of 1,200 r.p.m.

It should be particularly noted that the battery obtains sufficient charging current from the exciter during the normal running of the locomotive, but as the latter may, on occasions, be used in abnormal circumstances in out of the way localities, it is considered necessary to have an auxiliary for giving the battery periodical gassing charges to keep it in good condition.

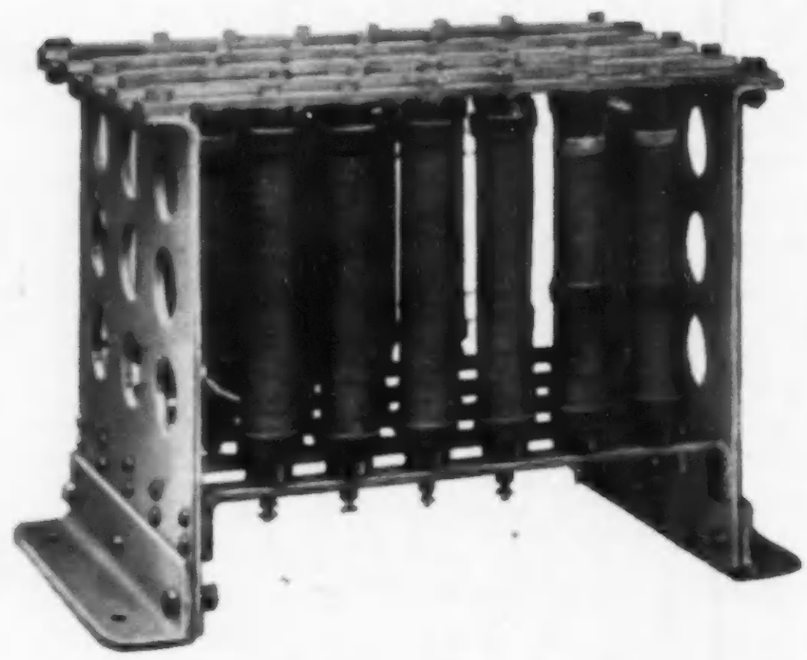


Fig. 16.—Main generator field control resistance.

BATTERY.

The battery installed in each locomotive consists of 50 cells, type K.L. 17, supplied by the D.P. Battery Co., Ltd., having a total capacity of 224 ampere hours at the 5 hour rate of discharge. The elements are fitted in strong ebonite containers designed to allow the free circulation of air round each cell.

BRAKES.

Each locomotive is equipped with separate vacuum and hand operated braking systems the controls of which may be seen on the left and right respectively of the master controller in the driving compartment, Fig. 4. For the vacuum brake a small D.C. motor drives a Reavell exhauster which requires approximately 3½ h.p. at normal speed and about 6 h.p. at high speed. Normally the motor is supplied with current from the exciter when the latter is running at 750 or 900 r.p.m., but at the two lower speed settings, it is fed from the battery.

Although this necessitates a rather more expensive arrangement than that of driving the exhauster directly off the main engine, the advantages gained by the system adopted are such as to give improved working and reliability. Moreover, the speed of the exhauster can be arranged to suit the brake conditions, entirely independently of the speed of the engine.

A driver's valve is provided which, when thrown into the full "release" position, automatically accelerates the exhauster for the release of the brakes.

CONTROL

The master controller is provided with an "off" position and eight steps as follows, in addition to a "forward" and "reverse" handle.

(1). Engine, 600 r.p.m., weak field generator, full field motor.

(2). Engine 600 r.p.m., full field generator, full field motor.

(3). Engine 750 r.p.m., weak field generator, full field motor.

(4). Engine 750 r.p.m., full field generator, full field motor.

(5). Engine 900 r.p.m., weak field generator, full field motor.

(6). Engine 900 r.p.m., full field generator, full field motor.

(7). Engine 900 r.p.m., weak field generator, weak field motor.

(8). Engine 900 r.p.m., full field generator, weak field motor.

Reversing is accomplished by means of the usual type of solenoid operated railway reverser, fig. 15, while other functions are carried out by means of contactors, the whole of which are operated from the master controller and are mounted on the various panels in the engine compartment. The main panel situated above the generator is illustrated in fig. 3 and the auxiliary panel in fig. 5. The connections of the lighting and auxiliary circuits are shown in fig. 8.

Interlocks are introduced in certain cases for the safety of the equipment, so that faulty connections cannot be made in the event of any contactor failing or remaining closed. In the "off" position the motor circuits are entirely broken by the contactors, M1, M2, M3 and M4 indicated on the diagram of the main circuit, fig. 9.

The setting of the engine governor is controlled by the valve coils T.350, T.600 and T.750 (*see* fig. 14). When all three valve coils are de-energised, the governor automatically floats back to the idling speed. In order to obtain an engine speed of 600 r.p.m. T.350 and T.600 must be energised; for 750 r.p.m., T.350 and T.750; and for 900 r.p.m., T.350 only.

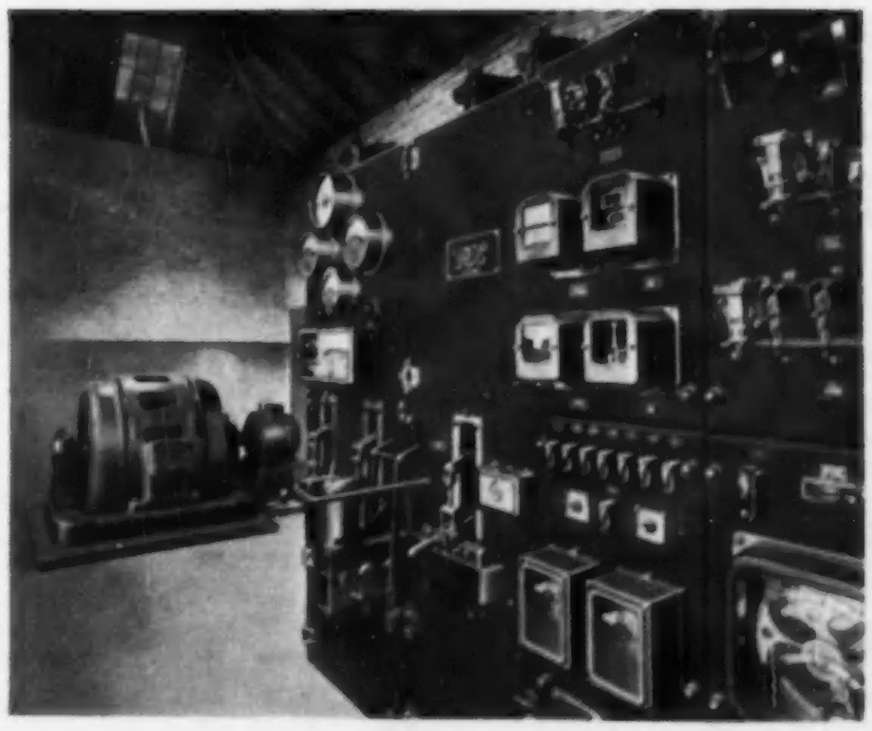
The master controllers are provided with the usual mechanical interlocking between reverse and main drums, and the engine is also safeguarded from being started under load by "off position" interlocks on the controller.

For the control of the field of the main generator, two sections of resistance, Fig. 16, are employed, one section being used only for the first step, thus facilitating suitable control of the locomotive when running light. The sequence of operation of the various contactors is clearly indicated in fig. 9 while the connections of the various control circuits are shown in fig. 14.

In conclusion it should be mentioned that the locomotives were built to the specification of the Consulting Engineers, Messrs. Rendel, Palmer & Tritton, the electrical equipment being manufactured throughout by the main contractors, The General Electric Co., Ltd., while the engines and mechanical portions respectively were constructed by their sub-contractors, Messrs. William Beardmore & Co., at their Parkhead and Dalmuir Works, Glasgow.

AUTOMATIC SYNCHRONOUS EQUIPMENT FOR AN IRONWORKS.

A 400 kVA, 3,300 volt, 1,000 r.p.m. synchronous condenser recently supplied to an ironworks in Scotland for the automatic regulation of power factor. The automatic control equipment includes relays for the starting and stopping of the machine with the rise and fall of load, and an automatic field regulator adjusts the excitation of the condenser to maintain unity power factor on the incoming supply.



Balanced Protection of High Tension Parallel Interconnectors.

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More attention is paid to the protection of transmission lines than to that of any other electrical equipment, chiefly because of the stringent requirements that have to be met. In the case of unbiassed schemes many difficulties have been experienced in complying with these requirements.

In this article is described a system installed on two 11 kV parallel inter-connectors between Oxford and Yarnton which has provided exactly the characteristics required.

WITH the great increase that is taking place at the present time in electrical distribution, it is natural that attention should be paid to the protection of feeders of all capacities. When so much depends upon the continuity of supply, it is most important that the transmission lines should be safeguarded to the fullest possible extent, and that any defect should be localised and isolated before serious damage has been done. If this can be accomplished effectively, the capacity and the extent of any distribution system may be enlarged indefinitely, without fear of more than the most local interruption, whatever faults may occur in any part of the insulation.

In deciding upon the type of scheme to be adopted for any particular case, there are several points which must be considered, the most important of which is the use of pilot wires. Since these auxiliary conductors are provided to establish communication between the incoming and outgoing ends of the equipment to be protected, they must extend the whole length of the line, and must in general involve considerable expense. On the other hand, they enable balanced protection to be employed with all its advantages of sensitivity, simplicity, and stability over the usual schemes which dispense with pilots. An alternative method is to instal split-conductor cables, the two halves of which are balanced against each other ; but these are also costly, and introduce difficulties in securing and maintaining uniformity between the two "splits."

There is one scheme, however, which enables balanced protection of a high order to be applied without the necessity for end-to-end pilot wires or other special conductors, and this is available when the distribution system consists of more than one feeder operating in parallel. It is then possible to design the relay system so that a comparison is made between the currents flowing in the two or more paths. Since the normal distribution between the several paths is upset by the existence of a fault, an easy and certain method is offered for tripping out the faulty section. While the split-conductor system operates on a similar principle, it can only treat the two paths as a single line, disconnecting both for a fault in either one. The great advantage of providing an alternative route is thus wanting.

So great are the claims of the parallel feeder scheme of protection that it is always adopted when lines are run in multiple, except in the unusual cases where reactors or special switches are introduced between divided bus-bars at either end. Now it is in any case a common practice to employ two or more feeders for important transmissions, and hence the chief requirement is very often met for reasons quite apart from the protective gear. It is then only necessary to instal protective equipment which is at the same time robust, free from elaborations, sensitive, selective and stable, in order that the results may be of the highest order in spite of the absence of special conductors.

Such a protective scheme, and one of more than ordinary interest, has now been installed for some months on a pair of parallel interconnectors, six miles in length, between the city of Oxford and Yarnton. These interconnectors, which differ from ordinary parallel feeders in that power may be fed in either direction, consist of underground cables run at a voltage of 11 kV, their normal carrying capacity being 4,000 kVA or 260 amps. each. They feed into an overhead system at 33 kV at the Yarnton end.

The distribution area is a new one, and the demand is at present in the process of building up, the principal load carried from Yarnton being the Cement Works at Shipton, supplied by two overhead feeders, while a third supplies Witney.

Before describing the protective scheme as applied to this installation, it will be of interest to consider briefly the general characteristics of the system of protection of which it is an example.

The three main principles of the system are that it is (1) balanced ; (2) biassed, and (3) selective.

In balanced protection the method of detection employed is the comparison of the currents flowing in different parts of the equipment. For example, if there is no leakage, the current entering the equipment corresponds exactly with that emerging. This principle enables the isolation of a faulty section to be effected as soon as a very low value of fault current has begun to flow. With the various systems depending on modified overload protection, on the other hand, operation cannot occur until the leak has considerably exceeded the normal full load current itself; while with those of the reverse power type, not only must the leak absorb all the load current, but an actual reverse flow into the distant end of the circuit must take place before protection can be given. It is, therefore, only by the use of the balanced system that the faulty section can be isolated before the fault has reached dangerous proportions.

Biassing is a method of automatically varying the sensitivity in accordance with the load. Without it, the insensitiveness that is necessary at high overloads, in order to obtain stability at times when current transformers are most likely to err in their ratio, is unavoidable at normal loads. Thus many feeders are still protected by balanced methods which will only operate for faults ranging from 150 to 250 per cent. of normal load; these should be compared with the standard values of 5 to 10 per cent. obtained by the system to be described.

The system is inherently selective, in that the faulty section only is tripped out without the use of time-lags or auxiliary relays. It can thus be definitely relied upon to shut down the minimum of equipment. In addition, the interruption is effected instantaneously, there being no need for the prolongation of dangerous conditions simply to give a certain relay time to trip before a number of others that may also tend to operate.

The services of protective gear would be very largely discounted if it were liable to interrupt the circuit improperly by tripping out a section with no fault, whenever there is one in another section. Accordingly, one of the chief requirements is that incorrect tripping must not occur. As has already been stated, stability during overloads or "through faults" must be given to the usual type of unbiassed scheme by employing a very high fault setting; and the stability of the relays employed may be indicated by means of a "stability ratio," or the ratio of the highest current which will not produce improper operation and the current at which it is set to trip. With the system under discussion, since the current required to bring about tripping increases with the load current, the instability point is never reached, however great the overload, and the stability "ratio" is infinity.

In all the schemes employing this system, current transformers are located in the conductors through which the currents flow that are to be balanced or compared. The secondaries of these transformers are joined to the special relays which make the comparison, and these latter close the trip circuits of the breakers when abnormal differences are registered.

The scheme as applied to the Oxford-Yarnton interconnectors is shown diagrammatically in fig. 1, in which both ends are shown, although the apparatus is similar at each end. It consists of a ring circuit in which the current transformers on each feeder are all joined in series, so that when all feeders are carrying equal current (that is, when all are sound), the secondary current flows round the main ring circuit and practically no current flows through the operating cores of the relays, which are connected in parallel with the transformers.

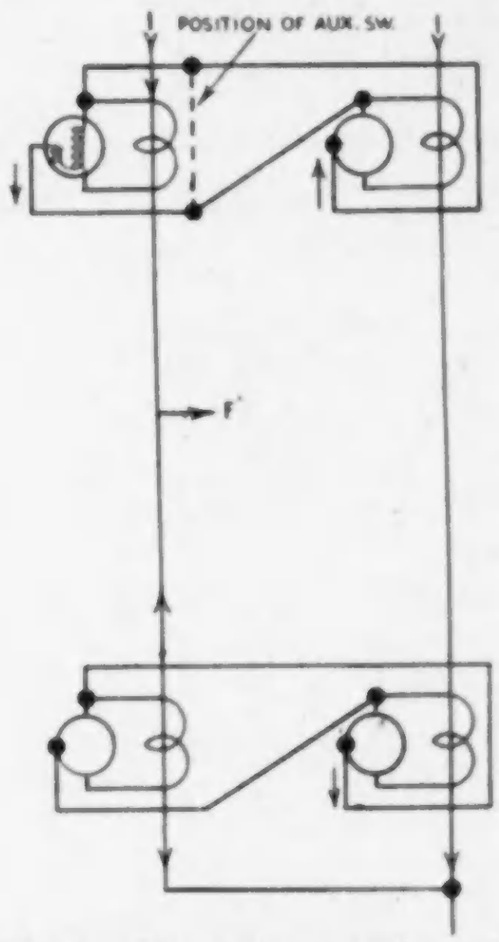

Fig. 1.—Diagram showing connections of current transformers at both ends of the interconnectors.

The new feature is contained in the design of the relay, which is of the directional type and except for a small addition is the standard reverse power relay. The addition consists of a small biassing electro magnet which is connected in the main ring circuit and therefore carries a current proportional to the load in the feeders. This magnet exerts a pull upon an armature attached to the end of a short arm fixed at the upper end of the relay spindle, and thus exercises a direct restraint upon the movement of the relay itself. Further, this pull is always positive and, hence, the restraint cannot reverse and so become an additional operating force when the power reverses in the feeder.

The addition to the standard reverse power relay is quite small and may clearly be seen in the space immediately above the scale in fig. 2. The relays,

as installed on the actual control board at the power station at Oxford, may be seen in fig. 3.

They are put out of action during paralleling and switching in by means of a switch operated by a removable handwheel supplied for this purpose, and

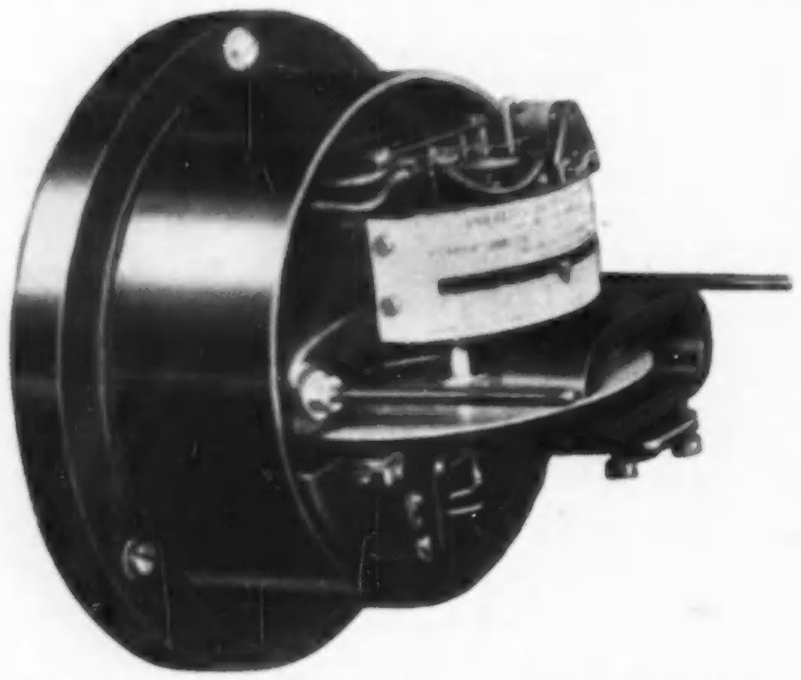

Fig. 2.—Directional relay with cover removed.

coloured red so that it would be extremely unlikely to be left in place after the switching operations have been completed.

The whole scheme was thoroughly tested in the laboratory before being installed, and facilities were afforded by the Oxford Electric Co., and the Wessex Power Co., for carrying out tests on site, these latter serving to endorse the excellent results obtained on laboratory tests.

Characteristic curves of the scheme are given in fig. 4, the first noticeable feature being the somewhat different results given by the relays at the two ends, the relay at the "home" end being always more sensitive than that at the distant end.

This is a new feature in protective gear, and is in accordance with the requirements of parallel feeder protection, where it is an advantage that the home relay shall operate first. In this connection it should be borne in mind that either end may be the home or the distant end, depending upon the direction of flow, and it is the latter alone that determines which of the relays shall have the lower setting. The result is achieved through the reversal of the voltage drop across the impedance of the smaller biassing magnet, which exerts a negative effect upon the bias at the home end and a positive effect at the distant end.

Secondly, it will be observed that the sensitiveness is of a very high order, the curves starting from a no-load value of 3 per cent., which is the value with the spring setting at the first division on the scale. The relay will operate with complete reliability at this point, and has been doing so in practice on the pair of parallel interconnectors to be protected. By moving the pointer to the other end of the scale, the no-load value of the curve can be raised to about 18 per cent. The difference between this and the existing curves decreases as the load rises, so that the extreme right hand end is not affected. This adjustment will be seen to be a valuable one. It should be observed that as high a fault setting at no load is not required for parallel feeders as for single feeders, since the capacity current, which produces its principal effect at no-load, is equal in all the feeders, and hence does not affect the balance of the scheme.

If the upper and less sensitive curves be examined, it will be seen that the high sensitiveness extends throughout the range of loads. At normal full load, the sensitiveness is 15 per cent. for the distant end, and 13 per cent. for the home end. These figures should be compared with the setting of 100 per cent. which is necessary for most other systems of parallel feeder or parallel interconnector protection.

Thirdly, there is a very big adjustment for bias, as is evidenced by the two sets of curves given. This is effected by simply moving the small biassing magnet to or from the armature in the slots provided for it. When the air gap between the pole piece and the armature is $\frac{1}{4}$in., the lower curves are given,

Fig. 3.—Control board at the power station of the Oxford Electric Co., Ltd.

in which the bias is practically zero, while when the gap is reduced to $\frac{1}{32}$in., the upper curves are obtained. It is of course not intended that the relays should operate on as low a bias as those in the bottom curve, which merely represents the extreme adjustment obtained.

Fourthly, the stability is very definite. This is

shown by the uniform slope of the operation curve, which indicates that the fault setting is increasing in a continuous manner as the load rises.

FINAL TESTS.

It will be of interest to give some brief details of the final tests recently carried out on site.

At the time that the tests were made it was found that between 78 and 80 amps. of load were available, of which 31 were passing into each Shipton feeder and 16 into the Witney feeder. The total load was, therefore, 1,500 kVA, which amounts to about one fifth the normal carrying capacity of the interconnectors.

The method of making the test consisted of producing an unbalance in the two feeders by taking advantage of the duplicate busbars in the power station. One feeder was connected to each bar, and a separate generator was run up to supply each. By field regulation of the generators, it was possible to load them unequally, and the unbalance was increased until operation occurred.

Since the unbalance was obtained by passing the same current right through the length of the feeder, and not by drawing off current at an intermediate point as would be done by a fault, the excess current flows in the opposite direction at the distant end as compared with actual practice. For this reason, while the more heavily loaded feeder trips out at the home end as under practical conditions, it is the other feeder which is the more lightly loaded and which trips at the distant end. This did not, however, prevent both ends being tested simultaneously.

The results corresponded exactly with those of laboratory tests. Tripping at both ends was very definite and uniform, the relays functioning every time the current was made to pass the operating value, and restoring when the unbalance was removed. This was done a large number of times, first one feeder and then the other being the more heavily loaded. It was observed that the three relays of the set moved their contacts simultaneously.

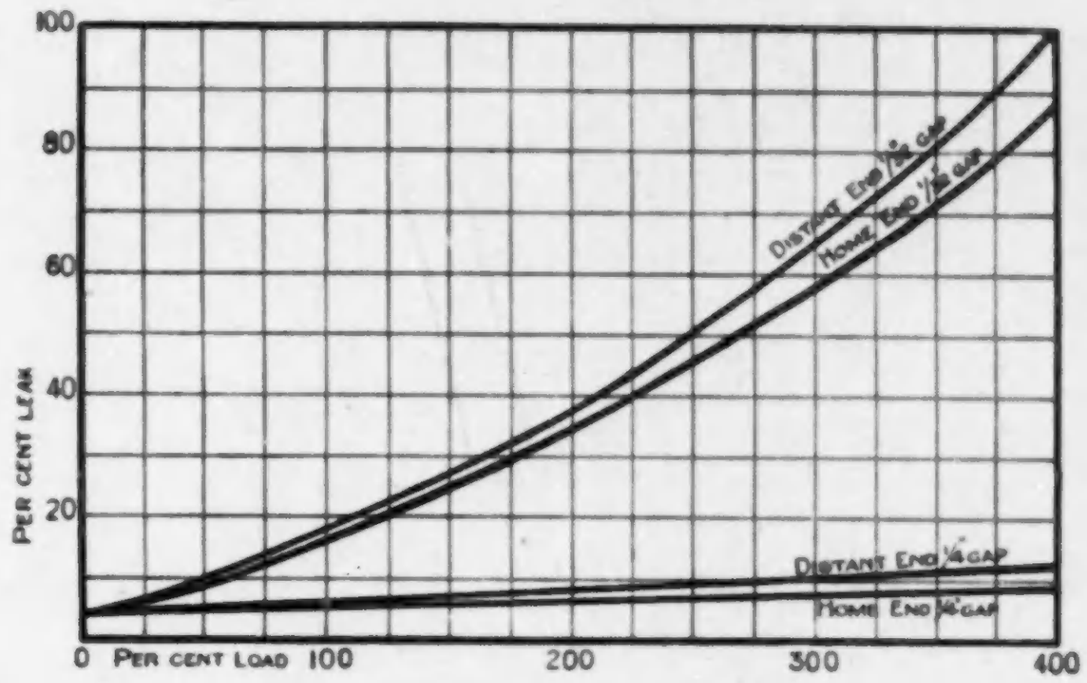

Fig. 4.—Characteristic curves of scheme.

A total of 78 amps. was passing through the two feeders during the tests, and the relays operated repeatedly when there was a difference of 12 amps. or 4.6 per cent. of the normal full load value. This point falls on the characteristic curve which had been ascertained for the relay, allowing for a no load value of three per cent.

The system was also subjected to an unexpected trial of a different kind on the day before the above tests were carried out. An insulator flashed over beyond the Yarnton end of the feeder, imposing a dead short circuit at this point. This caused a very heavy overload on the feeder, and therefore constituted a severe test on the stability of the protective gear.

There was no operation whatever, showing the system to be stable. This incident provided a very valuable test of the stability of the system, since it reproduced the worst conditions which the system can be called on to meet.

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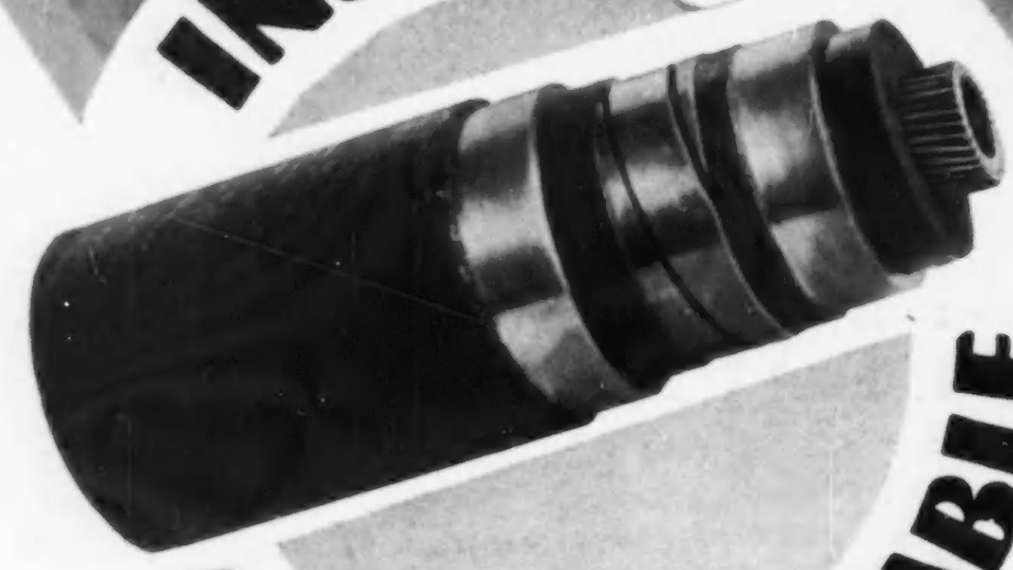

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